PRACTICAL ORGANIC CHEMISTRY

Companion Volume

A TEXTBOOK OF ORGANIC CHEMISTRY

The English Translation from the German of

A. BERNTHSEN, Ph.D.

New edition, edited and revised to date by J. J. SUDBOROUGH, Ph.D., D.Sc., F.R.I.C., formerly Professor of Organic Chemistry in the Indian Institute of Science, Bangalore.

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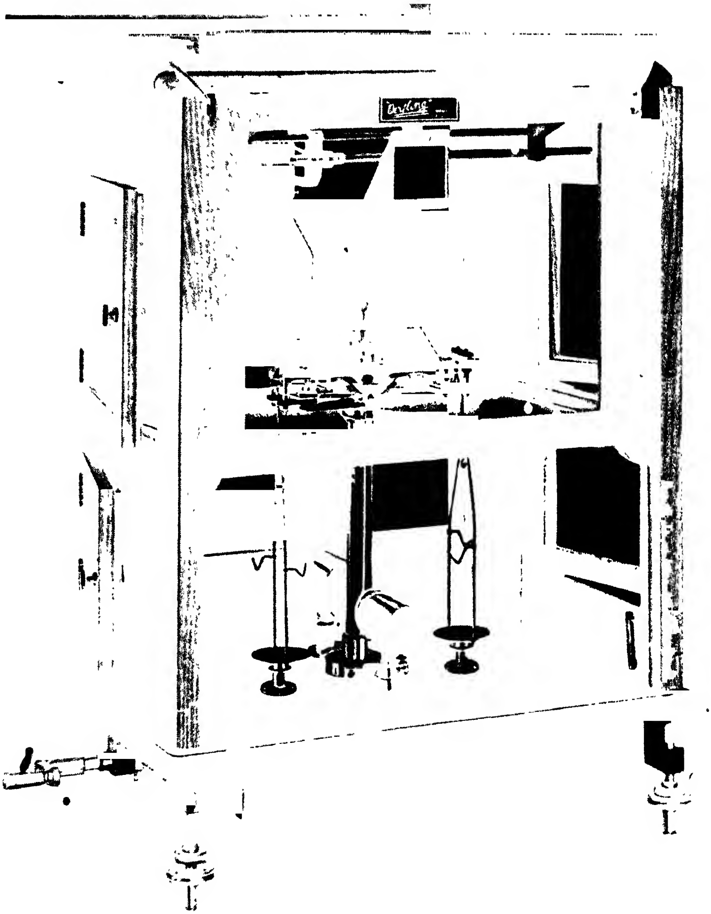

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Fig. 55.—Oertling microchemical balance

Frontispiece

PRACTICAL ORGANIC CHEMISTRY

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PREFACE

This work, first issued in 1909, is a laboratory companion to Sudborough's edition of Bernthsen's *Organic Chemistry.* The present edition has been completely revised in the light of long experience of the teaching of the subject, and an endeavour has been made to incorporate modern methods of quantitative analysis, new synthetic methods, and such processes of degradation of organic compounds as are useful in the determination of structure.

While the student is recommended to *read* each chapter fully and carefully, his director should suggest a sequence of experiments to be carried out. These should vary for different students so as to encourage individuality and initiative; but the properties and reactions of each separate type of compound should be carefully studied by all.

The section on recognition of organic compounds is not intended to serve the same purpose as tables of analysis in Inorganic Chemistry, but simply to suggest a line of approach to the subject. Here the preparation of suitable derivatives is of the utmost importance, and for this reason the tables of physical constants of such derivatives have been made more comprehensive than in previous editions.

We desire sincerely to thank those colleagues and friends who have suggested corrections and emendations and who have assisted in the revision of certain sections.

J. J. S.
T. C. J.

TORQUAY,
ABERYSTWYTH,

CONTENTS

ABBREVIATIONS

A.	Liebig's Annalen der Chemie.
A. Supp.	Supplement to Liebig's Annalen der Chemie.
A. Ch. Ph.	Annales de Chimie et Physique.
Am.	American Chemical Journal.
B.	Berichte der Deutschen Chemischen Gesellschaft.
B. A. Rep.	British Association Reports.
Bull.	Bulletin de la Société Chimique de France.
C.	Chemisches Zentralblatt.
Chem. Syn.	Chemical Syntheses.
C. N.	Chemical News.
C. R.	Comptes Rendus de l'Academie des Sciences.
C. Z.	Chemische Zeitung.
Gazz.	Gazzetta chimica italiana.
J.	Jahresberichte der Chemie.
J. A. C. S.	Journal of the American Chemical Society.
J. C. S.	Journal of the Chemical Society.
J. I. I. S.	Journal of the Indian Institute of Science, Bangalore.
J. pr.	Journal für praktische Chemie.
J. R. C. S.	Journal of the Russian Chemical Society.
J. S. C. I.	Journal of the Society of Chemical Industry.
L.-C.	Lassar-Cohn's Arbeits-methoden der Organische-Chemie IV Auflage.
M.	Monatshefte für Chemie.
P.	Proceedings of the Chemical Society.
Rec.	Recueil des Travaux Chimiques des Pays-Bas.
R. I. C.	Royal Institute of Chemistry.
S. B.	Sudborough's edition of Bernthsen's Organic Chemistry (1941).
Trans.	Transactions of the Royal Society.
T. R. S. E.	Transactions of the Royal Society of Edinburgh.
Z.	Zeitschrift für physikalische Chemie.
Z. A.	Zeitschrift für analytische Chemie.
Z. E.	Zeitschrift für Electrochemie.
Z. physiol.	Zeitschrift für physiologische Chemie.
D. R.-P.	Deutsch Reich-Patente.
d	dextro
l	lævo
dl	mixture of equal parts of *d* and *l*

o	ortho
m	meta
p	para
s	symmetrical
as	asymmetrical
Ac	Acetyl, $CH_3 \cdot CO$
Et	Ethyl, C_2H_5
Me	Methyl, CH_3
Ph	Phenyl, C_6H_5
R	Alkyl Radical
N	normal
g.	gram
ml.	millilitre

GENERAL PRECAUTIONS

1. **Fire.**—A student commencing the study of Organic Chemistry is liable to forget that most of his solvents and crystallizing media are highly inflammable. Thus the vapours of ether, light petroleum, carbon disulphide, acetone, alcohol, benzene, toluene, and glacial acetic acid are all inflammable. The risk of fire is considerably increased when the liquid used is very volatile, as part of the vapour may then escape condensation and take fire on coming into contact with a flame. One of the most dangerous liquids is carbon disulphide, as its vapour bursts into flame when brought into contact with a moderately hot surface, even in the absence of a naked light.

A wise precaution is to distil large quantities of ether, carbon disulphide, light petroleum, or acetone on a water bath heated by steam in a room in which no naked flames are allowed. If this is not possible a water bath should be heated by a flame, and the flame extinguished before the flask containing the volatile liquid is placed on the water bath. Another convenient method is to surround the flame with a wire cage (fig. 2, *d*), much in the same manner as in the Davy safety lamp. The vapour is condensed by means of a long condenser kept cool by means of running water (fig. 2, *b*).

2. **Dry Vessels.**—In many reactions good yields of products can only be obtained in the absence of water, and it is thus essential to have all the vessels, e.g. flasks, beakers, condensers, &c., quite dry. In other cases solvents are used which are not miscible with water, and it is essential that in such experiments dry vessels should be used. A simple plan is to wash each vessel after use, and to allow it to drain in a rack; as a rule it will then be dry and ready for use when required. A quicker method of drying vessels is to wash with water, then with alcohol, and to blow air through the warm vessel.

3. **Yields.**—An important point in all preparations is the question of yield. The most successful operator is he who obtains the best yield of pure product. An error made by

many students is to use an unnecessarily large number of vessels, and not troubling to remove as much as possible of the reacting mixture from the one vessel to the other. If a small residue, e.g. 2–3 per cent, of the total mixture is left in each vessel, the final yield of product may be considerably diminished.

4. **Poisonous Gases and Fumes.**—All experiments involving the use of poisonous gases and vapours (chlorine, bromine, halogen acids, methyl sulphate, &c.) and experiments in which the evolution of noxious fumes (halogens, acids, nitrous and cyanogen compounds) is probable *must* be carried out in a fume chamber provided with efficient draught.

5. **First Aid in case of Accidents.**—The laboratory should be provided with First-aid Box and Card of Instructions as issued by the Factory Department of the Home Office.

PRACTICAL ORGANIC CHEMISTRY

I. COMMON METHODS OF PURIFICATION

Before a detailed investigation of an organic compound is undertaken—whether this investigation be a determination of its composition and molecular weight, or an examination of its chemical and physical properties—it is essential that the compound should be pure. Some of the commoner methods of purification employed in the organic laboratory are described in this chapter.

A. Extraction with Ether and other Solvents

A method frequently resorted to in order to separate organic from mineral compounds is the process of shaking out with ether (S.B. 27).* Other solvents, such as chloroform and benzene, which are not miscible with water, are used occasionally. The method consists in shaking the aqueous liquid with a given volume of ether in a separating funnel (fig. 1), allowing the two liquid layers to separate, running off the lower aqueous layer by means of the tap at the bottom, and then pouring out the ethereal layer through the neck. By this means a complete separation of the two solutions can be effected. In all cases the aqueous liquid should be extracted a second time with ether, and the ethereal solution added to the first extract. The number of extractions necessary varies considerably with different substances, and depends on the relative solubilities of the substance in water and in ether.

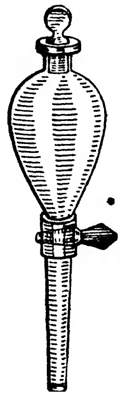


Fig. 1

* This refers to p. 27 in Sudborough's Edition of Bernthsen's *Organic Chemistry*.

For any given substance the ratio (*the distribution coefficient*)

$$\frac{\text{concentration of ethereal solution}}{\text{concentration of aqueous solution}}$$

is constant for any given temperature, provided the substance has the same molecular weight in the two solvents, and depends on the relative solubilities of the solute in the two solvents.

This ratio determines the number of times it is advisable to shake the aqueous solution with ether.

Experiment 1.—Make a saturated aqueous solution of succinic acid at 15° (cf. Solubility, Chap. III). Determine the concentration of this solution by titration with standard alkali, preferably barium hydroxide (Chap. VII, A), using phenol phthalein as indicator. Shake up the solution for some time with half its volume of ether at 15°, determine the distribution coefficient at this temperature, and then calculate how much of the acid will have been removed when the aqueous solution has been extracted 10 times, if in each extraction the volume of ether is equal to half the volume of the aqueous solution.

Theoretically the extraction is never complete, but in practice the amount remaining in the aqueous solution after several extractions is usually so minute that it may be neglected. The ethereal extract is usually dried by means of a relatively small amount of fused and powdered calcium chloride; this, however, cannot be employed if the ethereal solution contain an alcohol or an amine, as these form additive compounds with metallic chlorides. In such cases a suitable drying agent, e.g. solid potassium hydroxide, anhydrous sodium sulphate, or anhydrous magnesium sulphate must be used. The dry solution is decanted or filtered from the drying material, which is then washed with a little ether, and the ether removed by distillation (cf. General Precautions). The product thus obtained may be further purified by the methods described later. Some points deserving of notice in regard to ether extractions are:

(1) The metallic salts of acids and the salts of amines cannot, as a rule, be extracted from aqueous solutions by means of ether, although in many cases the acids and bases themselves are readily extracted.

(2) Certain metallic salts, especially halide salts, e.g. ferric chloride, stannous chloride, mercuric chloride, mercuric iodide, chromic anhydride, and the lead salts of unsaturated aliphatic acids, are fairly readily soluble in ether.

(3) Ether is soluble in water to an appreciable extent (8·1 per cent), and also water in ether; the aqueous layer which is drawn off is thus always saturated with ether. If the volume of the aqueous liquid is considerable, then the loss of ether due to its solubility is appreciable. This loss may be avoided, to a large extent, by previously saturating the aqueous liquid with common salt, as ether is less soluble in saturated sodium chloride solution than in water. The aqueous solution after extraction should not be heated over a free flame, as the ether vapour which is given off is highly inflammable (see General Precautions).

(4) If the ethereal solution is not dried before the ether is removed by distillation, the residue obtained contains appreciable amounts of water.

(5) As a rule it is best to use relatively small amounts of ether, as otherwise the distillation of the ether takes some time. If a number of extractions of the same solution have to be made, the volume of the ethereal extracts is usually large. To avoid using a very large flask when distilling off the ether, it is customary to run the dried ethereal extract into a small flask in portions by means of a dropping funnel (see fig. 2, *e*).

(6) When it is desired to make a quantitative estimation of the amount of product extracted, all the vessels, and also the calcium chloride used for drying the ethereal extract, should be thoroughly washed with ether, the ether removed from the total extract by slow distillation from a tared flask, and the residue finally dried in a desiccator. This method can be used with success only when the extracted matter is not readily volatile.

(7) In certain cases the ether and aqueous liquid tend to form an emulsion, and will not readily separate into two distinct layers. The addition of a small amount of alcohol will often bring about the separation.

B. Distillation

Liquids are commonly purified by the process of distillation, but the method is of use only when the substance boils without decomposition. By this means a substance may be freed from a non-volatile impurity, or from substances which are much more or much less readily volatile than the compound to

be purified (see Fractional Distillation). In the majority of cases the distillation is carried out under atmospheric pressure, but in cases where the compound decomposes when heated under atmospheric pressure, but is volatile without decomposition under reduced pressure, the process of distillation under reduced pressure (see p. 8) may be used.*

The ordinary process of distillation consists in boiling the liquid, usually in a glass vessel termed the *distillation flask*, *a*,

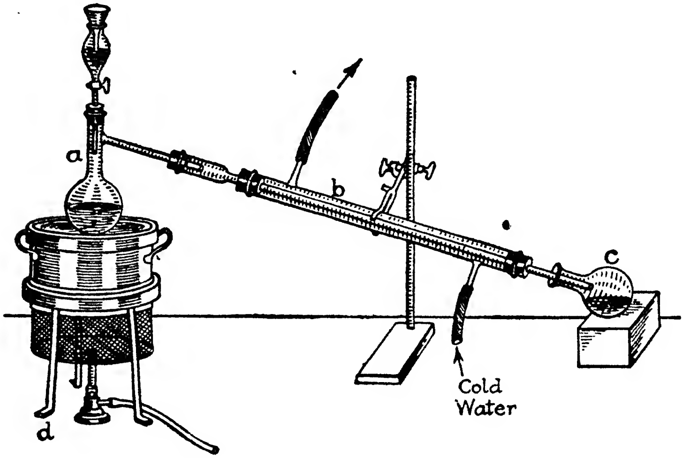


Fig. 2

condensing the vapour thus produced by means of a cool surface (*the condenser*, *b*), and collecting the condensed product in a *receiver*, *c* (see fig. 2). The distillation flask is usually a round-bottomed flask with a side tube fused into the neck; the neck is fitted with a cork which carries the thermometer, and the side tube is fitted to the condenser by means of another cork. It is essential that this connexion between flask and condenser should be tight, as otherwise a considerable portion of the vapour will not be condensed. In the majority of cases an ordinary Liebig condenser, i.e. a glass tube cooled by an outer jacket of running water, may be used; when the boiling-point of the substance is above 170° there is

* During recent years all-glass apparatus with ground-in joints has come largely into use, thus avoiding the use of corks and rubber stoppers for distillation and similar processes.

considerable risk that the inner condenser tube will crack, and an air condenser is therefore employed (cf. fig. 82). This consists of a straight glass tube similar to the inner tube of a Liebig condenser, and is cooled by contact with the surrounding air. When the boiling-point is very high, and only a small amount of liquid has to be distilled, a short air condenser made from a test tube may be used (fig. 3). Some points of interest in connexion with distillation are:

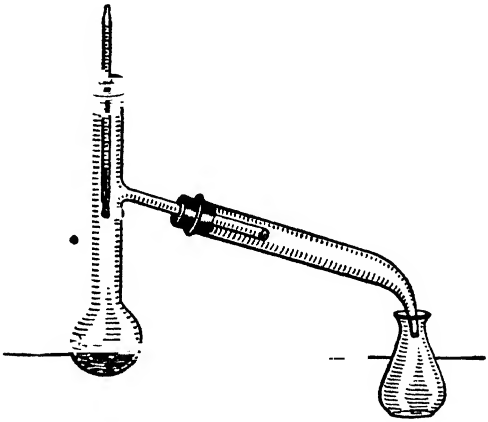


Fig. 3

(1) For high temperatures a round-bottomed flask should always be used. This may be heated directly with a small flame or by means of a small metal bath made of a readily fusible alloy, e.g. Wood's metal (Bi 4, Pb 2, Sn 1, Cd 1 parts).

(2) The main fraction which distils within a range of 2–3° should be collected separately, and may be further purified by a second distillation.

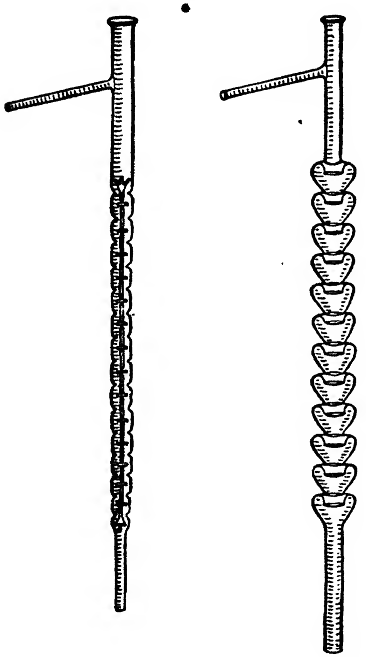
(3) In clamping a flask in which a substance of high boiling-point is being distilled the clamp should hold the flask at the coolest part of the neck, i.e. as far above the union of the neck and side tube as possible, otherwise the neck is almost certain to crack during the distillation, especially if tightly clamped.

(4) The bulb of the thermometer should be just below the position where the side tube is fused into the neck of the flask, and should not be immersed in the liquid.

(5) A simple method of preventing bumping and of securing even ebullition is to place two or three small pieces of porous pot in the liquid. These should be introduced before the liquid is heated, as if introduced into the hot liquid they may cause explosive ebullition.

(6) When the distillate tends to solidify in the condenser no special condensing tube should be attached. As a rule the substance will have a very high boiling-point and a moderately long, *wide* side tube to the flask will serve as a condenser, provided the distillation is not carried out too rapidly.

(See also Boiling - point Determinations, Chap. II, B.)



a b

Fig. 4

Fractional Distillation.—This is the method resorted to in order to separate miscible liquids the boiling-points of which are somewhat far removed from one another. The method is similar to an ordinary distillation, except that it is advisable to use a fractionating column. A long neck to the flask serves as a rough fractionating column, but the separation is more readily effected when a special column is used in conjunction with an ordinary round-bottom flask. Sidney Young* recommends the following forms (fig. 4): (*a*) rod and disc, (*b*) pear-shaped still head. They have the advantage that a fairly good separation can be accomplished by one distillation, and that very little liquid is retained in the column at the end. A simple form of column consists of a moderately wide tube with two or three bulbs blown on and a side tube. In fractionating it

* "Fractional Distillation", London, 1903, pp., 163, 165, 173.

is essential that the distillation should proceed slowly and evenly; it should always be possible to count the individual drops as they pass into the receiver.

The general method adopted will be best seen from the study of a concrete example.

Experiment 2.—The fractionation of "50-per-cent benzol" for the preparation of pure benzene and pure toluene.

100 g. of the mixture is placed in a round-bottomed flask provided with a still head, which is attached to a condenser and also fitted with a thermometer. The whole apparatus should be thoroughly dry and ten small dry flasks should be provided as receivers. The mixture is distilled by heating the flask with a small Bunsen flame, care being taken that the ebullition is quite regular, and that the condensed liquid does not drop into the receiver at a more rapid rate than one drop per second.

Separate fractions should be collected every 3° or 5° according to the efficiency of the still head, except with the first and last fractions which can be collected within a range of 1°. The following table gives the number of fractions and the corrected boiling-point for each fraction:

No.	Temperature (°C)	Weight		
		1st Distillation	2nd Distillation	3rd Distillation
1	80·2– 81·2			
2	81·2– 83·2			
3	83·2– 86·2			
4	86·2– 89·2			
5	89·2– 92·2			
6	92·2– 95·4			
7	95·4– 98·6			
8	98·6–101·6			
9	101·6–104·6			
10	104·6–107·6			
11	107·6–109·6			
12	109·6–110·6			
	Pure toluene 110·6°			

The weight of each fraction is noted.

The amounts of the different fractions will vary considerably according to the nature of the still head and of the rate of distillation. If necessary the distillation is repeated, fraction 2

being distilled in the same manner as the original mixture, but using a smaller flask. Any distillate passing over between 80·2° and 81·2° is collected in flask No. 1, and between 81·2° and 83·2° in flask No. 2. As soon as 83·2° is reached fraction 3 is added to the liquid in the distilling flask and the distillation continued, each fraction being collected in its proper receiver according to the temperature at which it passes over. When the temperature reaches 86·2°, fraction 4 is poured into the distilling flask and the operations are repeated until all 12 fractions have been redistilled. If the separation is still not sufficiently complete, the whole operation can be repeated a third and even a fourth time.

During the distillations the temperature should be kept as constant as possible; the flame must not be blown about and the distillation flask should be protected from air draughts.

It will not be possible to separate completely a mixture of two liquids which can give rise to a mixture of constant boiling-point. All that can be accomplished in this case is the separation of the excess of the one constituent from the mixture of constant boiling-point.

Distillation under Reduced Pressure.—This is always resorted to if the compound decomposes when heated at atmospheric pressure, but is volatile without decomposition at lower pressures; it is also used for separating mixtures which are difficult to separate by distillation under atmospheric pressure.

The usual method is to attach the flask and receiver to the condenser by means of air-tight corks. Rubber stoppers are preferable if they can be used; if, however, the liquid or its vapour attacks rubber, glass joints (see note p. 4) should be employed. It is more difficult to make these air-tight, one of the simplest methods being to coat them with collodion after the apparatus has been fitted up. The receiver is supplied with a side tube, e.g. an ordinary distilling flask or a small pump flask can be used, which can be attached to a water or mercury pump, and the pressure reduced to that required. As a rule the pressure used is the lowest obtainable with the pump; a good water pump gives pressures as low as 10–15 mm. of mercury. With a modern rotary pump pressures of 0·1 mm. are reached. To measure the pressure some form of manometer can be introduced between the receiver and the pump. A convenient form is that shown in fig. 5. In this the difference in level of the mercury in the two arms can be read by means of the

sliding mm. scale, and this gives the pressure under which the distillation is being conducted.

In distillations under diminished pressure the liability to bumping is much more pronounced than in ordinary distillations. This can be remedied, as a rule, by the introduction of a piece of porous pot; whenever the distillation is stopped

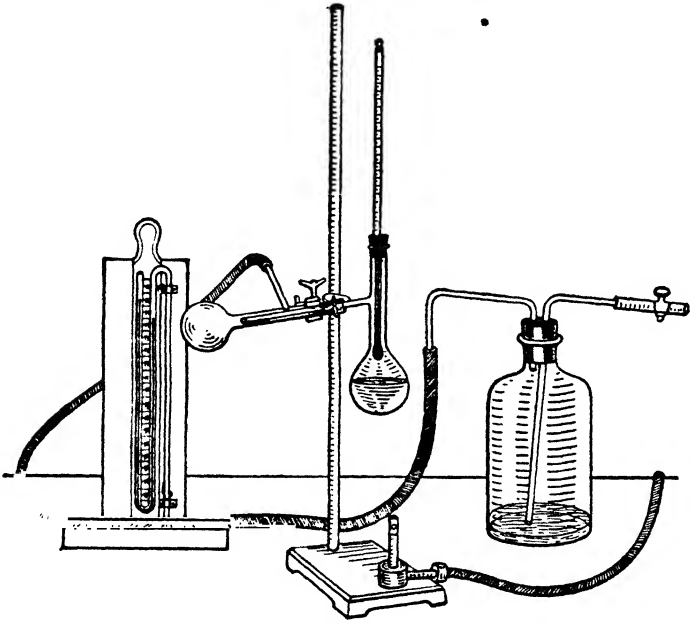


Fig. 5

and again started a fresh piece must be introduced, as it is the air-bubbles within the porous material which assist the evolution of bubbles of vapour. Another method adopted is to have a glass tube passing through the cork; this tube is drawn out at its lower end to a capillary which dips into the liquid, and can be closed by means of a piece of rubber tubing and small screw clamp at its upper end, so that the passage of air into the distilling flask is easily regulated. The drawback of this method is that it introduces an error in the boiling-point, as the pressure registered when air is present will be the sum of the partial pressures of the vapour and of the air.

In the majority of distillations under reduced pressure it is necessary to collect different fractions. One method of accomplishing this when the boiling-points are moderately high is to use a second distillation flask as receiver, and to fit up the two flasks as shown in fig. 5. The side tube of the receiver is attached to the manometer and pump, and is kept cold by a stream of running water. When the second fraction is to be collected the distillation is discontinued, the apparatus detached from the pump, and the receiver replaced by another

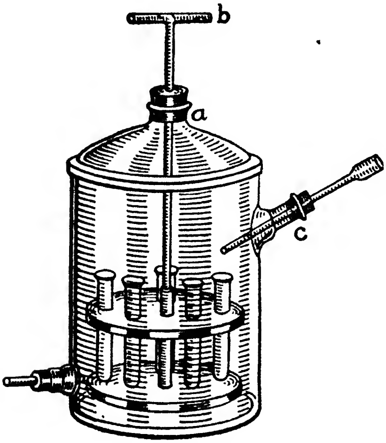


Fig. 6

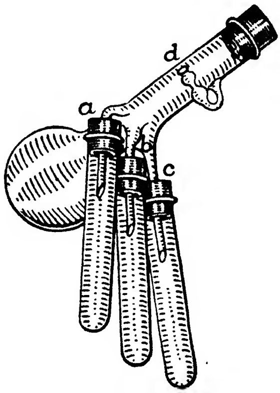


Fig. 7

similar flask and the redistillation continued when the pressure has again been reduced to the required value. Numerous forms of apparatus have been devised in order to obviate the necessity of interrupting the distillation while the receivers are being changed. The three following forms are those most frequently made use of: (*a*) Brühl's receiver, fig. 6. The condenser tube is introduced through the rubber stopper *c*, and projects into the apparatus, so that the drops of condensed liquid fall into one of the tubes provided as receivers. When the receiver is to be changed the stand and receiving tubes are turned through an angle by means of the handle *b*, whilst the cork *a* is firmly held. (*b*) Bredt's receiver, fig. 7. The condenser tube is fitted into the neck by means of a rubber stopper, and the outlet is just above one of the tubes *a*, *b*, *c*,

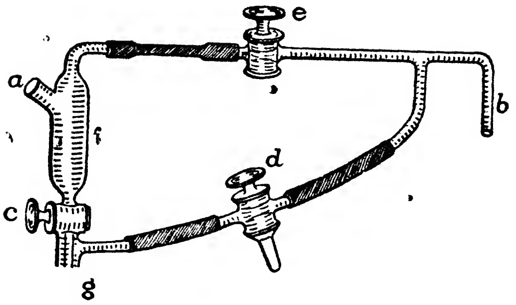


Fig. 8

to which stout test tubes or small flasks are attached by means of corks. The tube *d* is attached to the pump. The receiving tube is changed by turning the whole apparatus through a small angle. Both Bredt's and Brühl's receivers suffer from the disadvantage that if the liquid is fairly readily volatile portions of it collect in all the receivers, when only one is below the condensing tube. (*c*) The apparatus, figs. 8 and 9, is

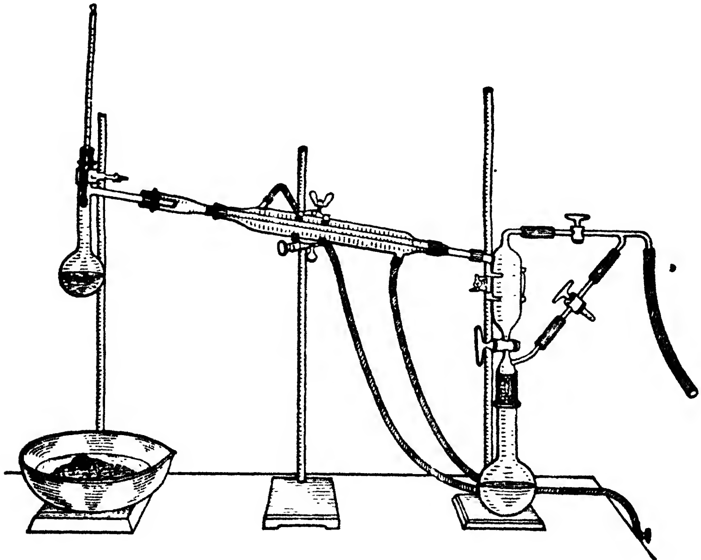


Fig. 9

one of the most convenient. In this case the condenser is fixed in *a*, and the pump and manometer are attached to *b*; usually a large bottle of about 10 litres capacity is placed between the pump and the manometer (as in fig. 5), as by this device the alterations in pressure during the changing of the receiver are not so marked. When the receiver is to be changed the cock *c* is turned off, *e* on, and the three-way cock *d* turned so that the receiver is connected with the outer air and not with the pump; the distillation can thus be continued and the distillate collected in *f*. When the new receiver has been attached to *g*, the cock *d* is turned, so that the receiver is connected with the pump and not with the air; after a short time cock *e* is closed and *c* opened, so that the distillate collected in *f* runs down into the new receiver.

Distillation with Steam.—This consists in blowing a current of steam through the substance to be distilled. It is only applicable to substances which have an appreciable vapour pressure at 100°, or just below. Another factor which determines the proportions of water and compound which pass over are their relative molecular weights. The method of blowing vapours other than steam, e.g. alcohol, toluene, &c., is not generally employed, as the molecular weights of these compounds are comparatively high for the temperatures which are attained, and the distillation would then be tedious.

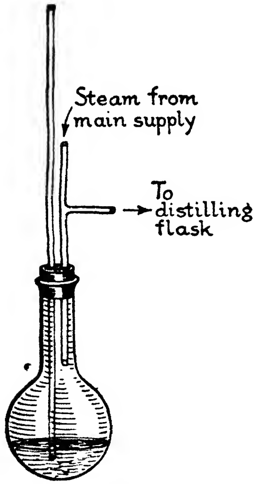


Fig. 10

The steam may be taken from the general laboratory supply, or generated in a metal can. In the latter case the can is provided with an ordinary safety funnel, or with a long glass tube which dips below the level of the boiling water. If the general laboratory supply is used it is necessary to blow this first through a vessel containing a small amount of water, and acting as a trap, e.g. fig. 10, otherwise alterations in the pressure of the steam may cause the liquid in the distillation flask to rush back into the steam pipe.

The material to be distilled is placed in a large round-

bottomed flask (fig. 11), preferably of resistance glass, and provided with a doubly bored cork or, if the vapours do not attack rubber, a rubber bung. The tube to carry the steam must dip below the liquid and is bent at obtuse angles at the upper and lower ends. The tube to carry off the steam and vapour is bent at a fairly sharp acute angle and fitted into the Liebig condenser by a cork or rubber bung. In this way the distillation flask is tilted on its side to a certain extent, and

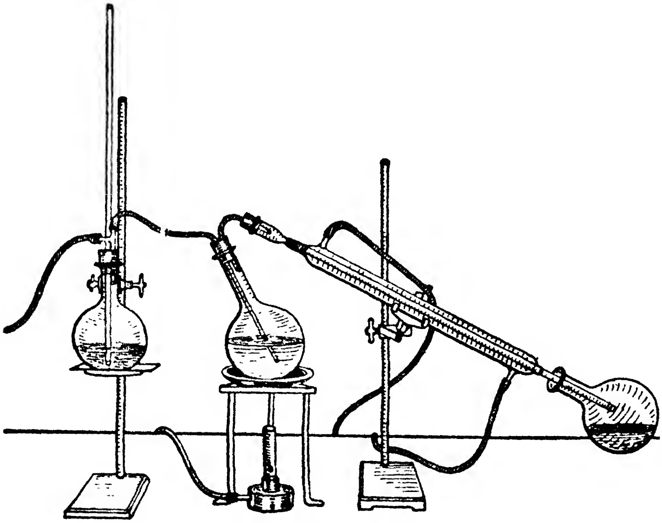


Fig. 11

when the ebullition is rapid there is not the same risk of liquid splashing up into the tube which carries the steam and vapour to the condenser. In order to avoid the condensation of large quantities of water in the distillation flask, it may be heated gently on a sand tray.

The product which distils over may remain dissolved in the water, e.g. acetic acid and the lower fatty acids, or may separate out as an oil (see Aniline, Exp. 150), or as a solid (see Orthonitrophenol, Exp. 116). In the latter case there is a risk that the solid which separates may choke up the condenser tube. This may be avoided by occasionally stopping the cold water from circulating around the inner condenser

tube; as the water in the condenser becomes warm the solid melts and flows down into the receiver, after which the cold water is again turned on.

It is comparatively easy to tell when the distillation is complete. If an oil or solid separates, the distillation is continued some 10–20 minutes after drops of oil or particles of solid have ceased to appear in the condenser. If the distillate contains a soluble acid, the distillation is continued until a few millilitres of the distillate no longer decolorizes dilute phenolphthalein solution coloured by a trace of alkali. To isolate the product from the distillate, one of the following methods is usually employed: (*a*) The solid is filtered off, and the filtrate extracted with ether, if the product is sufficiently soluble to render it worth while to extract the portion in the solution. (*b*) If the distillate separates as an oil, this is usually extracted with ether. If the volume of water is considerable, it is advisable to saturate with common salt before extracting with ether (see p. 3). (*c*) If the distillate contains a soluble acid, this may be exactly neutralized with sodium hydroxide or carbonate, and the solution evaporated to dryness, when the pure sodium salt will be obtained.

Distillation with Superheated Steam.—The method of procedure here is similar to that in ordinary steam distillation,

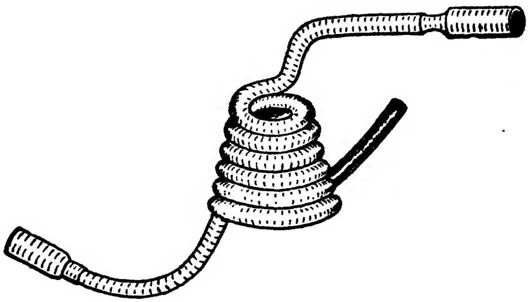


Fig. 12

except that the steam from the boiler is superheated before passing into the distillation flask. The usual method of superheating is to pass the steam through a coil of copper tubing (fig. 12) heated by means of a large burner. The boiling-point of the liquid in the flask may also be raised by introducing sulphuric acid or some substance which, with the water, will

give a solution boiling at 150°, 170°, or any special temperature required.

A simple electrical superheater may be made by taking a straight metal tube (iron or copper), 18 in. long and $\frac{3}{8}$ in. diameter, covering it with mica and asbestos paper, and winding over the paper 25 ft. of 28 S.W.G. Nichrome wire (resistance 70 ohms) in such a manner that the coils do not touch. The wired tube is finally covered with a suitable heat-insulating material, e.g. a mixture of moist magnesia and asbestos, and after drying, is covered with asbestos paper. By passing a suitable current through the Nichrome coil, steam passing through the metal tube may be superheated to any desired temperature between 105° and 200° C.

Rubber connexions cannot well be used with strongly superheated steam. The union between the copper coil and the glass steam tube leading into the distillation flask can be made by means of an ordinary cork. It is usually advisable for the stopper of the distillation flask to have three perforations, the third being used for a thermometer the bulb of which dips into the liquid.

C. Crystallization

The commonest method of purification of solid substances, whether obtained from natural sources or prepared in the laboratory, is by crystallization. The impurities present with the substance required may be (*a*) insoluble in the solvent used and will therefore remain undissolved, or (*b*) more soluble, in which case they will be left in the mother liquor after separation of the crystals.

The table (p. 16) gives a list of the more common solvents used in laboratory practice, together with their boiling-points and specific gravities.

During recent years the number of liquids available as solvents has been considerably increased by the introduction of many synthetic products which have found application in specific industries, e.g. for extraction of oils or as cellulose paint solvents. As examples may be mentioned *n*-butyl acetate (124–128°), *iso*-amyl acetate (138–142°), hexahydrocresol or sextol (160–180°), *s*-dichlorethane (83·5°), trichlorethylene (125°).

TABLE OF SOLVENTS

Solvent	B.P. (°C.)	Sp. Gr.
Benzene	80·2	0·8791
Toluene	110·6	0·868
Cymene	174	0·859
Cyclohexane	81	0·779
Light petroleum	40–60	
,, ,, ...	60–80	
,, ,, ...	80–100	
,, ,, ...	100–120	
Methyl alcohol	65	0·796
Ethyl alcohol	78·3	0·794
iso-Propyl alcohol	82·4	0·790
n-Butyl alcohol	113–119	0·814–816
iso-Amyl alcohol	128–132	
Acetone	56·2	0·791
Ethyl acetate	77·1	0·901
Acetic acid	118	1·055
Chloroform	61·2	1·490
Carbon tetrachloride	76–78	1·61–1·63
Pyridine	115	
Nitrobenzene	208	1·204

In the majority of cases the solubility of a substance in a given solvent increases with rise of temperature and the method of *crystallization by cooling* is usually employed. A nearly saturated, hot solution of the substance is made in the selected solvent and, on cooling, crystals separate which are removed by filtration.

Preparation of Solution.—The hot concentrated solution is prepared by warming the finely divided material with the solvent. If the substance is fairly readily soluble, this is accomplished by gently warming on the water bath; but if it takes some time for the material to dissolve, the mixture should be heated on the water or sand bath in a flask provided with a reflux condenser. In this way loss of solvent is avoided and also risk of the inflammable vapour of the solvent becoming ignited. If water or a liquid which is not readily volatile is used, the flask may be heated over the free flame; but if on warming the solid melts to a heavy oil which falls to the bottom, the flask and its contents should be shaken repeatedly, as otherwise the flask is liable to crack.

Care must be taken in the selection of the solvent, and also as regards the amount of solvent used. If the solvent to be used is not definitely stated, preliminary experiments are undertaken in order to find out which is the most efficient solvent. These experiments are made by placing a few centigrams of the material in each of several test tubes, and adding small amounts of the common solvents. If the substance dissolves immediately in the cold, or does not dissolve to any appreciable extent on warming, it may be concluded that those solvents are unsuitable.

If, on the other hand, the substance dissolves when the solvent is heated, but separates on cooling in a crystalline form, and to an appreciable extent, then that solvent may be selected. The following points should be noted:

1. In dissolving the substance previous to crystallizing, the amount of solvent should be so selected that crystals separate on cooling. If too much solvent is used, then the solution will not be saturated when cold and no crystals will appear. Certain solutions have a high degree of supersaturation and crystals do not readily separate. In such cases the deposition of crystals is facilitated by rubbing the sides of the vessel with a sharp glass rod, or even better by adding a small crystal of the substance, if such can be obtained.

A phenomenon frequently observed in a laboratory is the difficulty with which crystals are deposited when a substance is prepared for the first time, but in subsequent preparations crystals separate readily when the solution is exposed to the air for a short time. This is probably due to the fact that after the first preparation minute particles of the solid are present in the air, some of which are deposited in the solution, and act as nuclei around which the crystals grow.

2. It should be remembered that insoluble impurities are often present, and in these cases it is of no avail to add large quantities of the solvent in the hope of obtaining everything in solution.

Filtering the Hot Solution.—The hot saturated solution should not be filtered by means of a porcelain Hirsch or Büchner funnel (fig. 13, *b* or *a*) and the filter pump, as crystals invariably separate and block up the pores of the paper and the holes of the porcelain plate. If only a small amount of liquid is to be filtered, this may be done by using a funnel with a short stem and an ordinary filter paper, or a "folded"

filter paper (fig. 13, *c*), and warming both just before filtering. If the amount of liquid is considerable, it is advisable to keep the funnel hot during the filtration. This is most readily accomplished, provided the laboratory has a steam supply, by

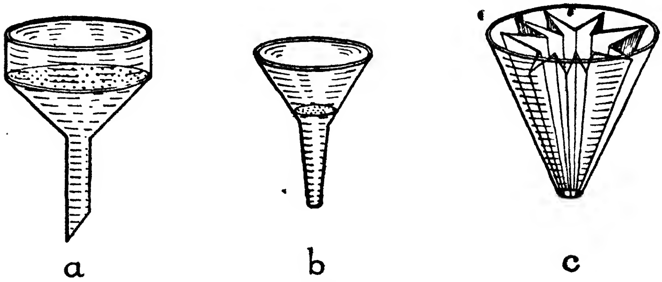


Fig. 13

allowing steam to pass through a metal coil which envelops the funnel (fig. 14). If a steam supply is not available, then the funnel can be surrounded by a large metal funnel, and the space between the two filled with hot water (fig. 15). The tube *a* is used for heating the water by means of a Bunsen

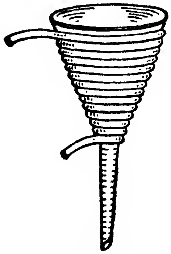


Fig. 14

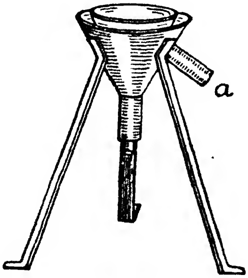


Fig. 15

burner, but a flame should *never* be placed under this tube during the actual filtration if the vapour of the solvent is inflammable. After filtration the paper is washed with a small amount of the hot solvent and the filtrate allowed to crystallize, preferably in a beaker.

Crystallizing.—To obtain large, well-developed crystals the vessel should not be disturbed, should be protected from dust by means of a filter paper or clock glass, convex side

upwards, and allowed to cool as slowly as possible. If small pure crystals are required for analytical purposes, the cooling should be as rapid as possible. This is effected by placing the beaker in cold water, or surrounding it with ice and stirring the solution. The crystals thus produced are very small, but, as a rule, are free from particles of mother liquor, which are very liable to be occluded in larger crystals. If the substance is too soluble at the ordinary temperature, crystallization may be facilitated by cooling the solution in an ice chest, or by means of artificial freezing mixtures, e.g. ice and salt or solid carbon dioxide. The methods given on p. 21 for facilitating the formation of the crystals can often be used on the larger scale. In certain cases an oil separates as the solution cools. If the solution is too concentrated, the solute may begin to separate at a temperature above its point of fusion. In many cases the temperature at which this occurs is below the melting-point of the pure substance. If the solute dissolves even a minute quantity of the solvent, its melting-point is appreciably lowered.

A substance which separates in liquid form may often be induced to solidify by drawing a stream of dry air over it by means of a suction pump at ordinary or lower temperature.

Removal of Crystals.—It must be borne in mind that the process of crystallization is used in order to purify a compound, and that the impurities are contained in the mother liquor; if this is allowed to evaporate completely, all the impurities are left with the crystals. If the crystals are large, the mother liquor can be removed by simple decantation and the crystals washed twice with a small amount of the pure solvent. As a rule it is much better to remove the mother liquor by filtration, using a porcelain funnel (fig. 13, *a* or *b*) and suction, and the crystals left on the funnel can be freed from adhering mother liquor by washing several times with small amounts of the solvent. If the liquid filters slowly the form of pump flask shown in fig. 16 is very convenient, as the stop-cock can be turned and the flask detached from the pump.

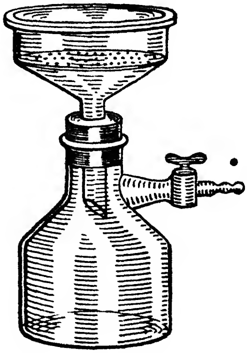


Fig. 16

The following points deserve attention:

(1) When a porcelain funnel with perforated plate is used the paper should be cut so as just to cover the plate. If the amount of material to be filtered is small, a small funnel is used and a stout test tube with a side tube in place of the pump flask.

(2) In removing the crystals from the beaker to the funnel care should be taken that crusts of solid matter which have been deposited on the sides of the beaker do not get mixed with the crystals. If possible these crusts should be removed before filtration.

(3) In washing the crystals with the pure solvent considerable care is required if the crystals are at all readily soluble. If too much solvent is used in such a case the crystals will completely dissolve. In all cases the crystals should be lightly pressed on the funnel by means of a spatula, and as much as possible of the mother liquor removed before washing is begun. A small amount of solvent is added, whilst the pump is detached and is then sucked through with the aid of the pump, and the operation repeated.

(4) When a high boiling or not very volatile solvent, such as nitrobenzene, glacial acetic acid, &c., has been used for crystallization, it is advisable to remove the whole of this and replace it by a more readily volatile liquid. This is done by washing first with the high boiling solvent, then with a mixture or mixtures of the two solvents, and ultimately several times with the volatile solvent, e.g. alcohol or benzene. As a rule the crystals obtained will be practically insoluble in these low boiling liquids.

(5) To dry the crystals they may be placed on filter paper and dried in the air, care being taken that they are protected from dust. They may be dried by being placed in a desiccator over calcium chloride, solid potash, or concentrated sulphuric acid. The drying in such a case is facilitated by partially evacuating the desiccator or by placing in the desiccator a material which will absorb the vapour of the volatile solvent, e.g. for benzene ordinary paraffin wax may be used. If the melting-point of the crystals is relatively high, and the solvent is not very readily volatile at the ordinary temperature, the crystals may be dried by placing on a watch glass in the steam oven or on the water bath. *Caution.*—Although the melting-point of the pure crystals may be considerably above

100°, yet in the presence of a small amount of a solvent they may melt below 100°.

(6) As a rule a second, and even a third and fourth lot of crystals may be obtained from the mother liquors, if these are evaporated to a certain extent. The crusts obtained in the first crystallization may be added to the mother liquor before it is evaporated. As a rule the later fractions will be less pure than the first fraction, and melting-points of each fraction should be determined, and only those fractions mixed which have practically the same melting-point.

Crystallization by Spontaneous Evaporation.—When the substance dissolves as readily in the cold as in the hot solvent no crystals will separate when the solution cools, even when the sides of the vessel are rubbed with a glass rod. The solution is still unsaturated, and if a crystal of the pure compound be added it will dissolve. The usual method of obtaining crystals from such a solution is to leave it to evaporate spontaneously at the ordinary temperature. The vessel employed, viz. a large test tube, beaker, or shallow crystallizing dish, depends upon the volatility of the solvent. The less volatile the solvent the wider and shallower the vessel used. The liquid should be protected from dust, usually by a funnel. Filter paper should only be used when it is known that the liquid shows no tendency to "creep" up the side of the vessel and over the edge. All the precautions as to mother liquid, filtering, washing, and drying crystals apply in this case.

Crystallization by Use of Two Miscible Solvents.—When a substance is too soluble in one solvent and not sufficiently soluble in another to admit of its being crystallized from either independently, it may be possible to crystallize it from a mixture of the two, provided they are miscible. The following pairs of solvents are frequently used for this purpose: alcohol and water, benzene and light petroleum, chloroform and light petroleum. The common method of procedure is to dissolve the material in the solvent in which it is readily soluble, to filter if necessary, and then to add the second solvent to the solution until a slight turbidity is produced. The mixture may then be warmed until it is quite clear and allowed to cool. In certain cases the substance separates as an oil, but in other cases in well-developed crystals. If it is necessary to allow the solution to evaporate before crystals

appear, it is essential that the solvent in which the substance is the more soluble should also be the more volatile. As evaporation proceeds the solvent becomes richer in the constituent in which the compound is less readily soluble, and after a time supersaturation occurs and crystals are formed.

Chloroform and light petroleum (b.p. 80–100°) form a good crystallizing medium for α-bromallo-cinnamic acid (Exp. 334). A mixture of alcohol and water is used for crystallizing *m*-dinitrobenzene (Exp. 114).

Substances which are extremely readily soluble in water, but insoluble in alcohol, may be dissolved in a mixture of the two solvents and the solution placed in a desiccator containing quicklime. This will absorb the moisture but not the alcohol vapour; the solution becomes richer in alcohol and crystals gradually appear.*

When a substance is very sparingly soluble in benzene, but readily soluble in a mixture of benzene and alcohol, it may sometimes be obtained in a crystalline form by dissolving in the hot mixture of benzene and alcohol, and then shaking the mixture with warm water. This removes the alcohol from the mixture and the substance then crystallizes from the benzene.

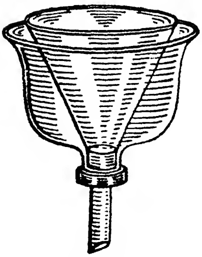


Fig. 17

Crystallization at Low Temperatures.—Occasionally the substance will crystallize from the solvent at temperatures below 0° only. The solution must then be placed in a freezing mixture, and whilst still cold must be filtered by means of a funnel surrounded by a freezing mixture (fig. 17). Under these conditions it is difficult to prevent moisture condensing on the cold materials, and thus the crystals cannot be kept free from moisture.

Fractional Crystallization.—The methods of crystallization already described apply to the purification of a single individual substance when mixed with small amounts of impurities. The process of fractional crystallization is resorted to when it is desired to separate two crystalline substances both of which are soluble in the solvent used. If there is a considerable difference in the solubilities of the two substances a partial separation may be previously effected by partial solution.

* *Rumpler*, B. 1900, 33, 3474.

The mixture is treated with an amount of the warm solvent insufficient to dissolve both substances. If the two substances are present in anything approximating equal quantities, the whole of the more soluble and a portion of the less soluble substance will be dissolved, and a considerable quantity of the latter left undissolved. The solution can then be subjected to fractional crystallization. This consists in collecting several fractions of crystals, either at different temperatures as the solution cools, or after given intervals of time when the solution is left to evaporate spontaneously. The number of fractions collected will vary with the different substances employed, but the following may be taken as a good general rule. Always remove a crystalline fraction by filtration when crystals of a type different from those already present begin to separate. If the fractions which are thus obtained are mixtures, they must be again dissolved and allowed to crystallize. The factors which mainly determine which of the two substances crystallizes first are: (1) The relative solubilities; as a rule the less soluble compound will separate first. (2) The relative amounts of the two. If a large quantity of the more soluble and only a very small amount of the less soluble compound is present, it is quite possible that the first fraction will consist of crystals of the more soluble compound.

In certain cases it is found that when the mixture is crystallized two entirely different types of crystals separate side by side. The only methods of separation in such a case are by mechanical means, e.g. difference in specific gravity; thus, if one set of crystals are feathery needles, and the others large prisms, a separation can often be effected by stirring the crystals with the mother liquor and rapidly decanting. The lighter needles are poured off with the liquor and the heavy prisms are left behind. As a last resource the separation of the two kinds of crystals may be accomplished by picking out the individual crystals by hand. This is generally tedious, but is comparatively easy when the crystals are large.

D. Extraction of Solids

A common method of separating solids is by extraction or fractional extraction. In a process of extraction it is advisable, if possible, to select as solvent a liquid which will dis-

solve the one constituent fairly readily and *leave the others* undissolved, or will dissolve everything except the substance required. If this method cannot be used, a method of fractional extraction must be resorted to. In a process of extraction it is often advisable to use as small an amount as possible of the extracting liquid, and this is accomplished by using the same amount of solvent over and over again. To accomplish this a piece of apparatus, termed the *extractor*, is introduced between the flask in which the extracting solvent is boiled and the condenser. A form of extractor commonly used for commercial purposes is the Soxhlet extractor (fig. 18).

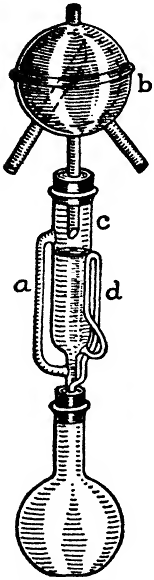


Fig. 18

The solid to be extracted is placed in the extractor; the solvent is boiled; the vapour passes along the side tube *a* into the condenser *b*, e.g. a globular metal condenser (Soxhlet condenser), and the condensed liquid collects in the vessel *c* until it reaches the level of the top of the siphon tube *d*, when it is automatically siphoned over into the boiling flask. The process is repeated, and thus the solid in *c* is continually being brought into contact with the pure solvent. After some time all the soluble matter will have been extracted, and the liquid in the boiling flask will be a solution of the extracted matter in the given solvent. After removal of the solvent by distillation the extracted matter can be obtained in a solid form. The common solvents employed are ether, carbon disulphide, and alcohol.

E. Sublimation

A method of obtaining solids in a pure crystalline form is by the process of sublimation. For this purpose it is essential that the substance in question shall have a high vapour pressure at comparatively moderate temperatures. Substances which can be readily purified by this method are trichlor- or tribromaniline, naphthalene, camphor, and benzoic acid. A simple method of sublimation consists in placing the impure material on a clock glass, covering this with a funnel or beaker,

and heating the clock glass gently on the water bath. The substance is volatilized, and the vapour is deposited on the cold inner surface of the funnel or beaker. If the substance has a low melting-point it often happens that the condensing vessel becomes warm, and the sublimed crystals melt. This difficulty may be overcome by cooling with water. One of the simplest forms of apparatus for this purpose is that suggested by Brühl (fig. 19). This consists of a flat hollow metal vessel with inlet and outlet tubes, and pierced in the middle by an opening of the shape of an inverted truncated cone. The substance to be sublimed is placed in a crucible in this cavity, cold water is passed through the metal vessel, a glass dish or beaker is placed over it, and the crucible gently heated.

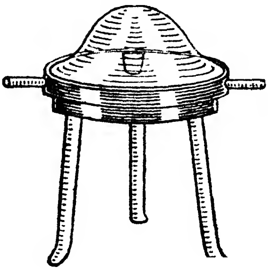


Fig. 19

A method of sublimation under reduced pressure has been devised by Diepolder. The apparatus (fig. 20) consists of a

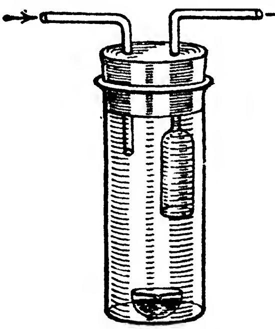


Fig. 20

hard glass tube fitted with a two-hole stopper, one hole carrying a capillary tube and the other a wide tube for collecting the sublimate, narrowing to a delivery tube for attachment to a pump. The substance is placed in a small beaker at the bottom of the hard glass tube, which is heated by immersion in a suitable bath. The air entering through the capillary is controlled by a screw clip. The apparatus is useful for purifying anthraquinone derivatives.

F. Chromatographic Adsorption

When a solution of a coloured compound is passed through a tube containing a finely divided, closely packed, colourless solid, the coloured substance is often adsorbed by the solid so that a coloured band, called a *chromatogram*, is formed in the tube. If the solution contains a mixture of coloured substances, a series of bands may develop, each consisting of an adsorption compound of the different solutes on the solid. The system may then be *developed* by treatment with portions of the same or another solvent and, when the bands are sufficiently distinct and separated from one another, the tube can be cut into sections and the coloured compounds recovered by extraction with a good solvent, and subsequent evaporation.

This technique, first applied by Tswett to the extraction of the colouring matter of leaves, &c., has proved to be very useful for the separation and purification of organic compounds generally. It may also be used for the purification of such colourless substances as show fluorescence under ultraviolet light, e.g. anthracene.

Almost any pale-coloured solid may be used as adsorbing agent, those most commonly used being activated alumina, oxides, sulphides or carbonates of calcium, barium and magnesium, powdered talc and fuller's earth. Organic compounds such as sugar have also been used in certain cases.

As solvents for the coloured solutes, petroleum ether, carbon tetrachloride, benzene, methyl and ethyl alcohols, ether and acetone may be used, adsorption being generally more complete the less the solubility of the solute in the solvent.

Experiment 3.—Separation of dinitrophenylhydrazones by chromatography.

Take a glass tube of about 1 cm. diameter and 50 cm. length, draw out one end so that it can take a short length of rubber tubing which is fitted with a clip and a tube passing into a suction flask (fig. 21). Introduce a plug of cotton wool into the narrow end, close the clip, and introduce 25 ml. of dry carbon tetrachloride into the tube. Add sufficient activated alumina gradually, stirring and pressing with a glass rod until a column of about 30 cm. length is obtained. Open the clip and apply gentle suction to remove most but not all of the liquid and again close the clip.

Prepare small samples of the 2:4-dinitrophenylhydrazones of benzophenone and dibenzylidene-acetone (Exp. 225). Weigh out 0·1 g. of each sample, mix and dissolve in 100 ml. of dry carbon tetrachloride. Introduce the solution into the prepared tube, open the clip, and draw the liquid slowly through the column by gentle suction. When nearly all has passed through develop with 100 ml. (or more if necessary) of dry solvent.


Fig. 21

Two distinct zones will appear in the column, the upper deep red and the lower orange in colour. When development is sufficient and the zones are clearly separated, suction is continued so as to dry the column. The tube is then removed and cut between the zones, the coloured bands removed and separately extracted with acetone. The extracts are filtered, the solvent evaporated, and the yields weighed. At least 80 per cent of each substance should be recovered. Benzophenone 2:4-dinitrophenylhydrazone (orange) has m.p. 239°; the dibenzylidene compound (red) 179°.

Many plant pigments, e.g. carotenes, α- and β-chlorophylls, can be extracted and isolated in a similar manner. Using ultra-violet light to detect the zones, anthracene may be purified.*

II. COMMON METHODS FOR TESTING THE PURITY OF A SUBSTANCE

A. Melting-point

A common method for testing the purity of a known compound is the determination of its melting-point. The introduction of small amounts of impurities almost invariably lowers the melting-point.† If, therefore, the melting-point is correct, the substance is usually taken as pure.

* For a detailed description of the technique and list of references consult *Cook*: "Chromatographic Analysis", R. Inst. Chem. Lecture, 1941.

† A few cases are known in which the introduction of an impurity raises the melting-point.

In dealing with an unknown compound it is usual to recrystallize it, if possible from several solvents, until its melting-point is no longer affected by subsequent recrystallizations. As a rule the compound will then have a sharp definite melting-point, and is considered pure. A few substances have somewhat indefinite melting-points; they begin to soften at a certain temperature, and are completely molten only at a much higher temperature; but, as a rule, a melting-point which is not sharp is due to the presence of an impurity.

The fact that the melting-point is sharp, and is not altered by subsequent crystallization, is not an absolute guarantee that the substance is a pure chemical individual. The possibility of the formation of mixed crystals always exists; such crystals will be formed during the crystallization of a mixture of isomorphous compounds, and no separation can be brought about by repeated crystallization from the given solvent. A well-known example is a mixture of the α- and β-monocarboxylic acids derived from thiophene when slowly crystallized from water. Such mixtures can frequently be separated by chemical methods.

The two methods commonly employed for determining melting-points are:

(1) Melting a comparatively large amount of the substance (20 g.) in a tube, and allowing the liquid to solidify with a thermometer in the mixture of liquid and solid. The melting-point, which is defined as the temperature at which the liquid and solid phases are in equilibrium, will be registered if the mixture of liquid and solid is kept well stirred. A standard thermometer should be used for the purpose, and a correction should be made for the portion of the mercury column which is not immersed in the solidifying liquid (see p. 30).

The thermometer can be clamped, and the liquid and solid intimately mixed by means of a ring stirrer which passes round the thermometer. Readings of the thermometer are taken every half-minute and recorded on a graph.

Experiment 4.—Determine the melting-point of *o*-nitrophenol by this method.

(2) For rapid determinations of melting-point the usual method is to place a small amount of the solid in a capillary glass tube closed at one end. This is attached to a thermometer and gradually heated in a liquid or air bath. Two forms of liquid bath are shown in figs. 22 and 23. For temperatures up to

240° the most convenient liquid is high-boiling (medicinal) paraffin.

In fig. 22 the temperature is kept constant by stirring; in fig. 23 no stirring is used, the substance in the tube is at the same level as the bulb of the thermometer, and the bulb of the flask is three-quarters filled with the liquid to be heated. The melting-point tube itself is made by taking a length of thin-walled glass tubing, heating a portion of it until quite soft in a blowpipe flame, and then, after removal from the

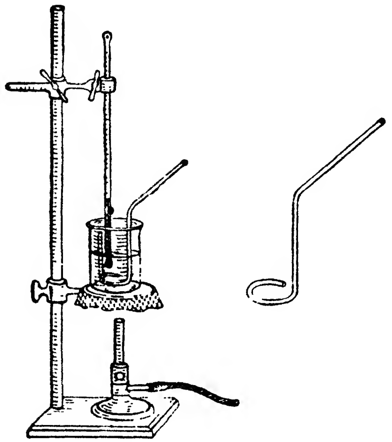


Fig. 22

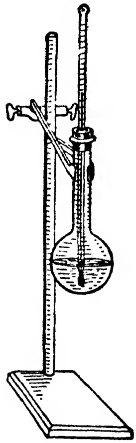


Fig. 23

flame, drawing it into a long capillary some 1–2 mm. wide. This long capillary can be broken by means of file marks into suitable lengths, and one end of each of these sealed up by holding the end of the tube in a Bunsen flame for a second or two. The substance is powdered and introduced into this tube; it may be made to fall to the bottom by gently tapping. The melting-point tube may be attached to the thermometer by (*a*) moistening the thermometer with a drop or two of the bath liquid, and then the tube will adhere by capillary attraction; (*b*) slipping a small rubber band (or a piece of narrow rubber tubing) over the thermometer and tube; (*c*) winding a piece of thin platinum wire round both.

The following precautions should be observed:

(*a*) Use only a small amount of the substance. The com-

mon mistake made is to use too much material; if this is done the temperature of the bath may rise through several degrees whilst the whole of the substance is melting, unless the temperature is extremely carefully regulated. A layer 1 mm. high is ample, and in certain cases it is better to place a portion of the powdered substance in the tube, to shake out the greater part, and to determine the melting-point of the portion which sticks to the inner surface of the tube.

(*b*) Use a standard (normal) thermometer, or an ordinary thermometer which has been calibrated by means of a normal thermometer. The commercial thermometers are occasionally inaccurate to the extent of two or three degrees.

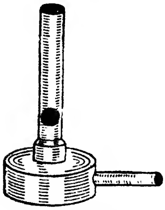


Fig. 24

(*c*) The temperature may be raised fairly rapidly until within a degree or two of the actual melting-point, but must then be raised very gradually, so that the melting-point may be read to half a degree. The simplest method of heating is by means of a micro-burner (fig. 24), which can be removed from time to time when the temperature approaches the melting-point.

(*d*) If the whole of the mercury thread of the thermometer is not immersed in the hot liquid, the temperature read off on the thermometer is not the correct melting-point, and should be corrected by means of the formula

$$t \text{ corr.} = t + 0{\cdot}000154\, a(t - t_0),$$

where 0·000154 is the apparent coefficient of mercury in glass, a is the length of thread measured in degrees not immersed in the hot liquid, t is the melting-point as read off on the thermometer, and t_0 is the mean temperature of the thread above the liquid. A simple method of obtaining correct melting-points is by using short normal thermometers, each ranging over some 50°, and taking care that the whole of the mercury thread is immersed in the hot liquid.

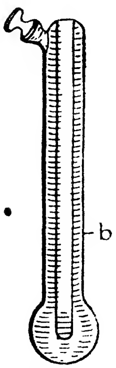


Fig. 25

Roth's apparatus (fig. 25) also admits of correct melting-points being taken. It is made of glass and has a perforated stopper to the side-neck to allow for expansion during heating. High-boiling paraffin is introduced through the side-neck to fill the annular space to the mark *b*.

On heating, the liquid expands and rises beyond *b*. The thermometer, with the tube containing the substance attached, is supported in the interior air-space by a cork, and will be at an even temperature along its length. The introduction of sufficient paraffin to cover the bulb of the thermometer is recommended.

In Mason's electrical melting-point apparatus,* the thermometer and tube containing the substance are suspended in a metal cylinder wound with a heating coil, and the melting-point is observed through an illuminated aperture.

It frequently happens that very different melting-points are obtained for the same substance owing to the different rates at which the substance is heated. Thus the melting-point of phthalic acid has been given at various temperatures ranging from 180° to 200°. This phenomenon is especially noticeable when the substance in question decomposes, e.g. gives up water, carbon dioxide, &c., on heating. In such a case it is advisable to raise the temperature of the bath to nearly the actual melting-point, and then to introduce the substance and raise fairly quickly until melting occurs. If the substance and thermometer are placed in a cold bath and the temperature raised slowly, much lower melting-points will be obtained; in the case of phthalic acid the reason for this is that as the acid is heated it loses water and yields the anhydride, and the melting-point registered will be that of a mixture of the acid and anhydride.

In other cases it has been observed that a given substance has apparently two distinct melting-points. When its temperature is raised it melts to a clear liquid, which immediately solidifies again, and on further raising of the temperature a second melting-point is observed. In such a case, unless careful observation is made, it is extremely easy to overlook the first melting-point and to observe the higher one only, as the substance usually resolidifies immediately after melting. The cause of this phenomenon has been discovered in most cases, namely, the conversion of the substance at its melting-point into an isomeride, or in some cases a product of decomposition with a higher melting-point. The actual melting-point of the compound is thus the lower temperature, the higher temperature corresponding with the melting-point of an isomeride or decomposition product.

p-Azophenetol melts in a characteristic manner. At 136° it

* Messrs. Gallenkamp, Ltd.

forms a turbid liquid which possesses several of the properties of crystalline substances, more especially double refraction; the turbid liquid is hence termed a *liquid crystal.* At 165° the melt becomes quite clear, and then possesses none of the above-mentioned properties.

Melting-points are occasionally determined in tubes open at both ends, e.g. in the case of a wax which is most easily introduced in a liquid state; or in a tube closed at both ends, more especially when the substance under examination sublimes (e.g. fumaric acid) or decomposes (e.g. dibromosuccinic acid) when heated in a tube open at the upper end. If a melting-point is determined under these conditions it should be clearly stated, as the melting-points in open and closed tubes are not always the same.

Melting-point Curves of Mixtures.—Melting-point curves of mixtures are valuable as indicating whether combination occurs between the two constituents of the mixture, and also for telling the composition of the compound, if such is formed.

The melting-point curve is obtained by plotting the melting-points of various mixtures against the molecular percentage composition of the mixtures. A mixture containing known weights of the two components is made, and the melting-point determined. The weights taken are transformed into molecular percentages. This is done by dividing the actual amount of each substance by its molecular weight, and then expressing as percentages. The method of determining the melting-point of the mixture varies somewhat. Philip* determines the freezing-point by the Beckmann method (Chap. VIII, B), i.e. the temperature at which the fused mixture begins to solidify. Kreman,† on the other hand, using a Beckmann freezing-point vessel, warms the mixture until a clear liquid is just obtained and reads off the temperature, care being taken that the mixture is thoroughly stirred as the temperature is raised. The temperature of the liquid is then raised several degrees, and the melt placed in an air bath and stirred whilst the temperature falls until the mass begins to solidify. The mean of several such determinations of solidifying and melting-points is taken as the correct equilibrium temperature.

The type of curve in figs. 26 and 29 is that usually obtained when the two compounds do not unite to form an additive compound, and consists of two branches with an

* J. C. S. 1903, **83**, 814. † M. 1904, **25**, 1230.

eutectic point. The type in figs. 27 and 28 is that obtained when the constituents form an additive compound. In both the cases given the compound formed consists of an equal number of molecules of each constituent; the curve consists of three branches with two eutectic points. The highest point in the middle branch is the melting-point of the definite

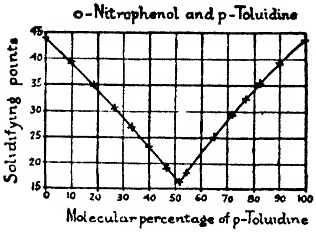


Fig. 26

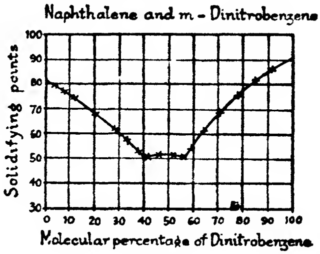


Fig. 27

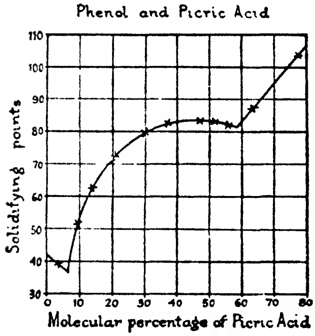


Fig. 28

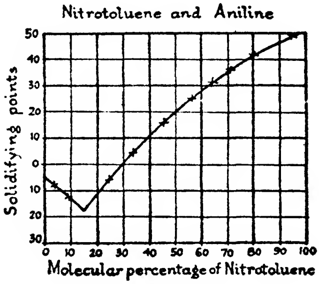


Fig. 29

compound consisting of an equal number of molecules of each component. The addition of a further amount of either constituent produces a lowering of the melting-point. The nature of the middle branch often indicates the degree of stability of the compound; if the compound is sufficiently stable to be readily isolated, the middle branch forms the greater part of the whole curve, as in fig. 28, and rises and falls abruptly. Where the compound is extremely unstable the middle branch of the curve is smaller and is much flatter in appearance (fig. 27). If the two components can form

more than one compound, then there will be more than three branches, and the maxima of the middle branches will give the melting-points and molecular compositions of the compounds formed.

The formation of mixed crystals complicates the study of melting-point curves.

Experiment 5.—Determine the melting-point curve of one of the following mixtures: (*a*) phenol and α-naphthylamine; (*b*) α-naphthol and *p*-toluidine; (*c*) naphthalene and picric acid; and state what conclusions you draw from the nature of the curve.

B. Boiling-point

The boiling-point, i.e. the temperature at which the liquid and its vapour are in equilibrium, may be determined by the following methods:

I. Distilling the liquid under ordinary or under reduced pressure and noting the temperature at which distillation occurs. If the compound is pure and is volatile without decomposition, practically the whole of the liquid will pass over at a constant temperature; when only a small amount of liquid remains in the distilling flask the vapour will, as a rule, become superheated, and a temperature rather higher than the correct boiling-point will be registered. The apparatus used is similar to that described under distillation (Chap. I, B.), and attention may be drawn to the following points:

(1) The thermometer should be a normal one, and the whole of the thread of mercury should be in the vapour; if a portion of the thread is surrounded by cold air a correction must be made for this (p. 7). If short thermometers, similar to those used in melting-point determinations (p. 27), are employed, it is generally easy to fix the thermometer so that the whole thread is immersed in the hot vapour.

(2) The bulb of the thermometer should be in the vapour just below the side tube; it should not be immersed in the liquid.

(3) Superheating of the vapour must be avoided. Low-boiling liquids should not be boiled on a water bath if a correct boiling-point is required, as the steam issuing may surround the flask and superheat the vapour. As a rule, a small direct flame from a micro-burner (fig. 24) is best, and even this should be so regulated that the flame only comes into contact

with the portion of the flask filled with liquid. On no account should it lick round the flask and come into contact with the portion where the vapour is present.

The bulb of the thermometer should always be covered with a thin film of pure liquid produced by the condensation of the vapour on the thermometer; this thin film of liquid will be in equilibrium with the pure vapour, and the correct boiling-point will be registered. Certain authorities recommend wrapping a small piece of cotton wool round the bulb of the thermometer in order to secure a film of liquid on the bulb.

(4) Bumping may be avoided and regular boiling facilitated by the introduction of one or two pieces of porous pot.

II. **Smith and Menzies' method** may be used when only a small quantity of substance is available, and may also be used to determine the vaporizing point of solids which do not melt. A modified form of their apparatus is described below. A length (20 cm.) of capillary tubing (bore 1–2 mm.) is taken and a small bulb (0·5–1·0 cm.) is blown at a point about 5 cm. from one end. The capillary tube is then sealed just below the bulblet and bent as indicated in fig. 30. The liquid, the boiling-point of which is to be determined, is introduced into the bulblet by gently heating the latter, immersing the open end of the tube in the liquid and allowing to cool. Solid material is best introduced before bending the shorter limb. The object of the sealed longer limb is to permit the apparatus to be clamped to a suitable stand from which the thermometer is also suspended. The whole apparatus is immersed in a beaker containing a suitable liquid and so clamped that the bulblet and the whole of the shorter limb are well immersed. Suitable liquids are water or concentrated calcium chloride solution, sulphuric acid and melted paraffin wax (m.p. about 53°). The bath is heated and as the boiling-point is approached it is stirred vigorously and a few bubbles of air are expelled.

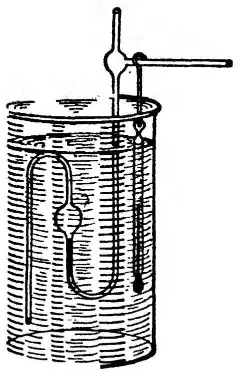


Fig. 30

When the actual boiling-point is reached all the air in the bulblet is quickly expelled and, provided the substance is not soluble in the bath liquid, bubbles of the vapour from the

boiling liquid rise to the surface of the bath in a rapid and regular stream. The lowering of the temperature by the fraction of a degree, by removing the flame, interrupts the stream sharply, and a re-elevation, by the same amount, restores it. The reading is taken when, with very slowly falling temperature accompanied by vigorous stirring, the stream of bubbles ceases.*

C. Specific Gravity

The specific gravity of a liquid is usually a good criterion of its purity, and may be determined by means of a pyknometer or Sprengel tube. In either case the vessel must be filled

Fig. 31

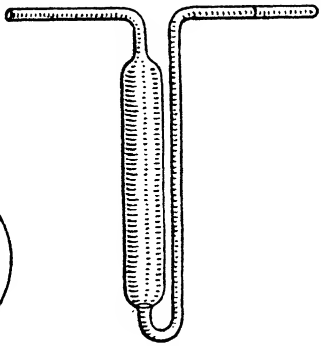


Fig. 33

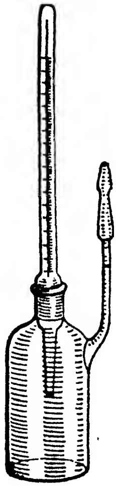


Fig. 32

with the liquid at a definite temperature. This is accomplished by filling the vessel at a slightly lower temperature and keeping it for some hours in a thermostat at the temperature required; the increased volume of the liquid due to expansion passes through the hole in the stopper or through the end of the Sprengel tube (fig. 33), and can be removed by filter paper. The weight of the given volume of liquid com-

* J. A. C. S. 1910, 2; see also *Belcher*, Microchemistry, R. Inst. Chem. Lecture, 1946.

pared with the weight of the same volume of pure water is the specific gravity, and is denoted by D. The temperature at which the determination was made and also the temperature of the water with which the comparison was made are also denoted, e.g. $D^{20°}_{4°} = 1{\cdot}3204$ indicates that the specific gravity of the liquid in question at 20° is 1·3204 when water at 4° is taken as unity.

In the vessels shown in figs. 32 and 33 marks are placed on the side tubes, and the experiment is always arranged so that the liquid meniscus coincides with this mark when the liquid is at the given temperature.

Experiment 6.—Determine the specific gravity of ethyl alcohol purified as described in Exp. 23, or of benzene as purified in Exp. 2.

III. SOLUBILITY OF SOLIDS IN LIQUIDS

The solubility of a given solid in a solvent indicates the number of grams of the solid which dissolve in 100 g. of the solvent to yield a *saturated solution* at the temperature stated.

1. **Solubility at the Ordinary Temperature.**—A saturated solution may be prepared by making a fairly concentrated hot solution, and cooling down this solution by placing in a vessel of water at the ordinary temperature, care being taken that the solution is thoroughly stirred as it cools, and that solid separates. If solid does not separate, the solution may be either unsaturated or supersaturated. To facilitate the separation of solid, a small crystal may be introduced and a rough glass rod used for stirring. The solution is kept in the water bath for 2 hours, then again vigorously stirred, and finally a suitable amount filtered through a dry filter paper. The first 1–2 ml. of solution which pass through the paper should be discarded as they are usually not completely saturated. The filtrate which then passes is collected in a weighed crucible, weighing bottle, or other suitable vessel provided with a lid, and the amount weighed. The volatile solvent is then removed by careful evaporation and the dry residue weighed, the weighings being repeated until the residue after cooling in a desiccator is constant in weight. The solubility of a substance which is appreciably volatile at the

ordinary or slightly higher temperatures, e.g. *p*-toluidine, cannot be determined by this method. The best method for volatile substances is to prepare the saturated solution, and then to determine the concentration of the solution by some chemical method, e.g. of an acid solution by titration.

Another method of obtaining a saturated solution is to shake the finely powdered solid with the pure solvent in a stoppered bottle for *at least* several hours. The shaking may be carried out by means of any ordinary shaking machine, care being taken to note the temperature; an even better method is to shake in a water thermostat at a fixed temperature. In the latter case the bottle is attached to a rotating axis in the thermostat, the axis being rotated by means of a water turbine, hot-air motor or electromotor.

If the solvent employed is very volatile it is advisable to avoid filtration; this may be accomplished by removing a portion of the clear solution by means of a pipette, provided the solid readily falls to the bottom and leaves a perfectly clear solution above.

2. **Solubility at High Temperatures.**—In the determination of the solubility at high temperatures the saturated solution cannot be filtered in the ordinary manner, since the solution cools during the process and part of the solute crystallizes. The simplest form of apparatus is that due to Pawlewski* (fig. 34). It consists of a test tube A, 10 × 2 cm., and a weighing bottle B, both provided with rubber bungs with two holes. The solvent and solute are placed in A, and B is empty; the bent tube E has its longer limb reaching nearly to the bottom of A, and the end of this limb is covered by two or three layers of fine linen which are firmly tied on.

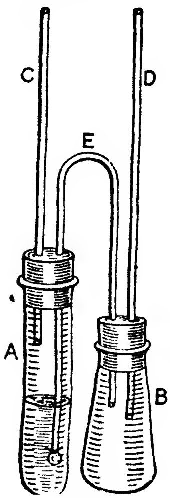


Fig. 34

The whole apparatus is suspended in a thermostat at constant temperature, air is drawn out through C so that the solute and solvent are thoroughly mixed. When the solution is saturated the tube D is attached to the pump and a portion of the saturated solution drawn off into B, the layers of linen serving as a filter.

* *Pawlewski*, B. 1899, **32**, 1040.

The apparatus is disconnected, B dried on the outside, the glass stopper replaced, and the whole weighed. If necessary small condensers can be attached to C and D. The method cannot be used for substances which are readily oxidized nor yet for very volatile solvents.

Experiment 7.—Determine the solubility of potassium oxalate in water at four different temperatures, and construct a solubility curve for this salt. Use two different methods for determining the concentrations of the saturated solutions.

For more accurate work refer to Findlay's *Practical Physical Chemistry*.

IV. DETECTION OF THE COMMON ELEMENTS WHICH OCCUR IN CARBON COMPOUNDS

The common elements which have to be tested for are carbon, hydrogen, nitrogen, halogens, sulphur, and phosphorus, and, in the case of metallic salts of organic acids, the common metallic radicals.

A. Carbon and Hydrogen

The only sure positive test for carbon and hydrogen is oxidation to carbon dioxide and water respectively and testing for these. The oxidation is conducted in a dry glass tube by means of *dry* cupric oxide.

A small amount (·1 to ·2 g.) of the liquid or solid is mixed with freshly ignited powdered cupric oxide and placed in the end of a somewhat narrow hard-glass tube 4–5 in. long and closed at one end. Two or three inches of dry granular cupric oxide are added, and the mouth of the tube closed with a cork and delivery tube. The tube is heated gradually, beginning at the front end, so that the layer of granular oxide of copper is quite hot before the substance itself is heated. Moisture can be detected by its condensation in the form of drops of water, or by placing a small amount of anhydrous cupric sulphate in the front part of the tube. Carbon dioxide is detected by passing the products of combustion into lime water or baryta water.

In testing for hydrogen it is essential that all the materials

should be dry, and as cupric oxide is hygroscopic it is necessary to heat this thoroughly just before use. Certain carbon compounds char when heated alone or with concentrated sulphuric acid, but this test is of no value as a negative test, as numerous volatile carbon compounds do not char under these conditions.

B. Nitrogen

(*a*) The liquid or solid is heated with soda lime, and ammonia is tested for in the issuing gases. The reaction may be used as a simple positive test, but is of no value as a negative test, as numerous compounds, e.g. nitro- and diazo-derivatives, &c., do not evolve their nitrogen in the form of ammonia under these conditions.

(*b*) A small amount of the substance is heated with a small pellet of metallic sodium or potassium. The mixture is heated gradually, in case the reaction is brisk, and then as strongly as possible. The mistakes frequently made by students in this test are—using too large a quantity of the substance and not heating sufficiently. If the compound is volatile and does not readily react with the metal, it simply boils and the condensed vapour falls back on the molten metal and remaining substance without reacting. The amount taken should be such that the whole of it can be vaporized in the small tube, and the sodium can thus be heated much above the boiling point of the substance. When a drop of the liquid falls back into the strongly heated metal decomposition occurs, and if nitrogen is present sodium cyanide is formed. When once formed this is not destroyed by heat, and the tube should be heated until the glass begins to melt. When comparatively cool the tube is broken and the whole mass extracted with a little water,* filtered if necessary, and the alkaline liquid warmed with ferrous sulphate solution, and then acidified. If nitrogen was present in the original substance a bluish-green coloration or a blue precipitate of Prussian blue is obtained. The reactions which take place are the production of sodium ferrocyanide from the sodium cyanide and ferrous hydroxide,

$$6NaCN + Fe(OH)_2 = Na_4FeC_6N_6 + 2NaOH,$$

* Care should be taken in case any metallic sodium or potassium still remains.

and the production of ferric ferrocyanide (Prussian blue), $Fe_4(FeC_6N_6)_3$, when the solution is acidified, owing to small amounts of ferric salt produced by the oxidation of the ferrous sulphate.

The method does not give satisfactory results when sulphur is also present, and it is then advisable to add a fair amount of iron powder to the substance before it is heated with sodium or potassium (Jacobsen). According to Täuber,* nitrogen can be detected by this method when compounds quite free from nitrogen are used, as the iron acts as a nitrogen carrier and the atmospheric nitrogen is transformed into cyanide. Täuber recommends using a large excess of potassium, e.g. 2 g. freshly cut potassium for some ·02 g. of substance, and finds that under these conditions sulphur does not interfere.

Nitrogen in diazo- and certain pyrrole derivatives cannot be detected by this method.† The following method ‡ is stated to work in all cases. A mixture of two parts by weight of ignited potassium carbonate and one of magnesium powder is used in place of metallic potassium; the mixture probably reacts in such a manner as to liberate metallic potassium when heated:

$$K_2CO_3 + 3Mg = 2K + C + 3MgO.$$

Another advantage of this method is that the mixture can be prepared in large quantities and stocked ready for use. A few mg. of the mixture is intimately mixed with the carbon compound, and then heated in a porcelain crucible or in a glass tube sealed at one end. The mass is ultimately extracted with water, filtered, the filtrate rendered alkaline with sodium hydroxide solution, and tested for cyanide in the usual manner.

C. Halogens

The following methods are used:

(1) A piece of pure copper oxide (e.g. a piece of wire-form cupric oxide, such as is used in the estimation of carbon and hydrogen), which can be held by means of a piece of platinum wire wound round it, is moistened with the substance and held in the lower outer edge of the Bunsen flame. The presence of halogen is indicated by the green coloration imparted

* B. 1899, **32**, 3150. † B. 1902, **35**, 2523.

‡ *Castellana*, Gazz. 1904, **34**, (2), 359; *Ellis*, C. N. 1910, **102**, 187, states that the reagent absorbs atmospheric nitrogen.

to the flame. Even volatile halogen derivatives give the reaction. If the substance is a solid, the cupric oxide is gently warmed and dipped into a small portion of the solid (Beilstein).

(2) A small amount of the substance is heated with metallic sodium (as in testing for nitrogen), or with a larger amount of pure lime in a glass tube. The heated mass is afterwards extracted with water, acidified with nitric acid, the solution filtered and boiled (to remove cyanide), and the chloride, bromide, and iodide ions tested for with silver nitrate solution.

(3) A mixture of sodium peroxide with 25 times its weight of a compound rich in carbon and hydrogen (e.g. naphthalene or cinnamic acid) is prepared and stocked in a bottle with a good stopper. In carrying out the test a small amount of this mixture is heated, by means of the Bunsen flame, with a few particles of the substance in a glass or, better, iron tube. When cold the mass is extracted with water, the clear solution acidified with nitric acid, and tested in the usual manner. Phosphorus may also be tested for by mixing a portion of the acidified liquid with ammonium molybdate. If a portion of the clear extract is acidified with hydrochloric acid, sulphur may be tested for by the addition of barium chloride solution.

N.B.—The sodium, lime, or sodium peroxide used in testing for halogens should always be previously examined for halogens.

In each case, when the presence of halogen has been established, the exact nature of the halogen, i.e. chlorine, bromine, or iodine, should be determined.

D. Sulphur

(1) The presence or absence of sulphur is readily indicated by taking a portion of the clear alkaline filtrate obtained in testing for nitrogen (method *b*), and adding a drop or two of sodium nitroprusside solution. The production of a brilliant evanescent purple coloration is a sure indication of the presence of sulphur.

(2) The substance is oxidized, extracted with water, the clear extract acidified with hydrochloric acid, and the sulphate ion tested for by means of barium chloride solution. The methods of oxidation are as follows: (*a*) With sodium peroxide, as in testing for halogens. (*b*) When the substance is not too vola-

tile, by fusion with sodium carbonate and potassium nitrate. (*c*) The substance is dissolved in hot potassium hydroxide solution, and then chlorine is led in; after some time excess of hydrochloric acid is added, the mixture boiled, and then tested for sulphate ions. (*d*) The substance is heated with fuming nitric acid in sealed tubes.

(3) **Middleton's method** * for nitrogen, sulphur and halogens. *The reagents should be of Analar quality* and blank tests should be made for nitrogen and halogens. The ignition tube is made from ordinary glass tubing ¼ in. diameter, and has a small bulb at the closed end. The reagent is a mixture of zinc dust with half its weight of anhydrous sodium carbonate. A small amount of the substance is mixed with about five times its bulk of this reagent, introduced into the bulb and covered with the reagent so that in tapping the tube there is a column of about 1 in. above the bulb. The top portion is heated first and finally the bulb containing the mixture to a red heat. While hot plunge into water (10 ml.) in a porcelain basin, heat to boiling, and filter, and make the following tests:

(*a*) For sulphur, nitroprusside test and silver coin test.

(*b*) For nitrogen, by warming with ferrous sulphate and observing whether Prussian blue is formed on acidifying. (Cf. Section B(*b*).)

(*c*) For halogens, by adding concentrated nitric acid and silver nitrate. If nitrogen is present add excess of $HgNO_3$ solution (5 per cent) and after the black coloration has disappeared a permanent white precipitate indicates a halide.

E. Phosphorus

The usual method is to oxidize to phosphoric acid, and to test for this by means of ammonium molybdate. The oxidation can be effected, as in the case of sulphur, by means of (*a*) sodium peroxide, (*b*) sodium carbonate and nitrate, (*c*) nitric acid under pressure.

F. Detection of Common Metallic Radicals in Organic Salts

As a rule the organic matter is destroyed and the residue examined for the common metallic radicals in the usual

* Analyst, 1935, 154.

manner. The organic matter may be destroyed: (*a*) by heating to redness for some time in contact with the air, either on platinum or porcelain. *N.B.*—Platinium must not be used when lead, silver, mercury, &c., are present. Any volatile substances, e.g. mercury, arsenic, and ammonia, will be lost during the heating. (*b*) By oxidation with a mixture of concentrated nitric and sulphuric acids. This process is quicker, as no charring occurs.

V. ESTIMATION OF THE COMMONLY OCCURRING ELEMENTS BY MACRO METHODS

A. Estimation of Carbon and Hydrogen

All the methods which have been adopted for estimating carbon and hydrogen in organic compounds are based on the general principle of oxidizing to carbon dioxide and water and either measuring or preferably weighing the amounts of these formed. The first quantitative experiments were made by Lavoisier (1784), who actually burned the material in a suitable lamp. Gay-Lussac and Thenard (1810) and Berzelius (1814) used potassium chlorate as the oxidizing agent, while Gay-Lussac (1815) adopted cupric oxide for the same purpose. Liebig (1831) introduced the method and apparatus which are essentially the same as those used at present, and was the first chemist to obtain results which can be regarded as accurate.

The oxidation is brought about by oxygen and cupric oxide and is carried out in a hard-glass tube heated in a suitable furnace. Liebig used a charcoal fire, but later various types of gas or electric furnaces were introduced. The water is estimated by absorption in weighed calcium chloride tubes, and the carbon dioxide in potash bulbs or soda-lime tubes.

The Tube.—The tube used should be of hard glass or of silica, open at both ends, the external diameter being 12–20 mm. and the length about 10 cm. longer than the furnace. The tube should be clean and dry and its ends fitted with rubber stoppers each with a single hole,* care having been

* The glass tubes which are introduced into these stoppers should be pushed in until the end of the tube is just flush with that end of the stopper which fits into the combustion tube.

taken that the rough edges of the ends of the tube are filed smooth or are rounded by heating in the blowpipe flame.

The tube is filled as shown in fig. 35; *a* and *b* are coils of copper gauze each about 2 cm. long; they should be free from grease, and should just fit easily into the tube; they serve to keep the long layer, *c* (some 45 cm. long), of wire-form cupric oxide in position; *d* is a coil of copper gauze some 15 cm. long, which has been strongly heated so that its surface is completely oxidized. The space between *b* and *d* is reserved for the boat which is to hold the substance for analysis. The tube and its contents are dried by passing a stream of dry air through the tube while it is heated in the furnace, and the end *f* protected from atmospheric moisture by a straight calcium chloride tube. The air used should be freed from moisture and carbon dioxide by passing it first through a wash bottle containing concentrated sulphuric acid, and finally through a soda-lime tower and a U tube filled with granular calcium chloride. A convenient form of apparatus for this purpose is the one shown in fig. 36, which can be used for drying both air and oxygen. This is a great advantage, as occasionally both gases are required at different times in the same combustion, and by means of the clips at *a* and *b* it is possible to admit either gas into the U tube, which is connected to a glass tube passing through the rubber stopper at *e* (fig. 35).

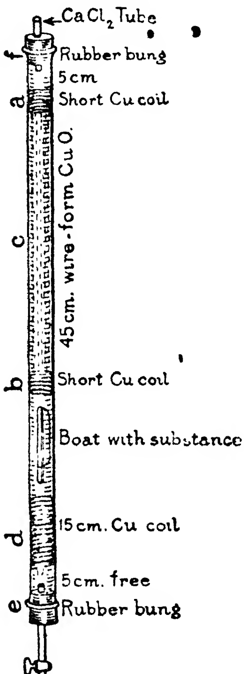


Fig. 35

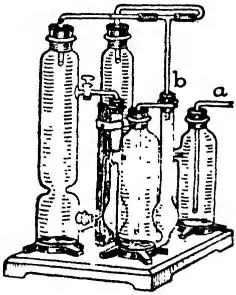


Fig. 36

Collecting the Products of Combustion.—The water is usually collected in a calcium chloride tube (fig. 37), although some

chemists use a similar tube filled with pumice and moistened with concentrated sulphuric acid. The side tube *a* fits into the rubber stopper which closes the end *f* of the combustion tube (fig. 35). A common mistake made is to attach the drying tube by means of rubber to a glass tube passing through the stopper at *f*. If this is done it is impossible to weigh accurately the water produced, as part of it will collect in the glass tube and rubber connexion. The side tube *b* serves to connect the calcium chloride tube to the apparatus for absorbing carbon dioxide.

After the tube is filled with *granular* calcium chloride and covered with glass wool, the neck *c*, fig. 37, or *c* and *d*, fig. 38,

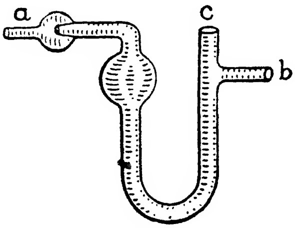


Fig. 37

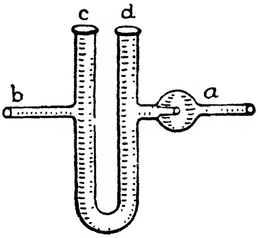


Fig. 38

is closed, either by sealing off in a blowpipe flame or by corks pushed down into the necks and covered flush with the top with molten paraffin wax or sealing wax, which is then allowed to solidify. When not in use the tubes *a* and *b* are closed *by means of short lengths of stout rubber tubing* provided with plugs of glass rod. In this manner the calcium chloride may be protected from atmospheric moisture. Before the tube is used the first time, dry carbon dioxide is passed through, as the chloride is apt to contain basic chlorides which absorb carbon dioxide; after the gas has been passed for some 1·5 hr. it can be replaced by dry air and the tube is then ready for use. For the purpose of weighing, the tube is suspended to the hook on the balance by means of platinum or aluminium wire. Before weighing, the tube should be dusted and the rubber caps removed. These caps should never be weighed with the tube, as rubber is hygroscopic and varies in weight according to the amount of moisture in the atmosphere. The same rule applies to weighing the apparatus in which

the carbon dioxide is collected. In all unions made by means of rubber tubes, whether the union of the calcium chloride tube to the potash bulbs or the union between the drying apparatus and the tube which leads the dry air into the combustion tube, care should be taken that the gas which has to pass the union does not come into contact with any considerable length of rubber—this is easily arranged by having the ends of the two glass tubes touching one another inside the rubber tubing.

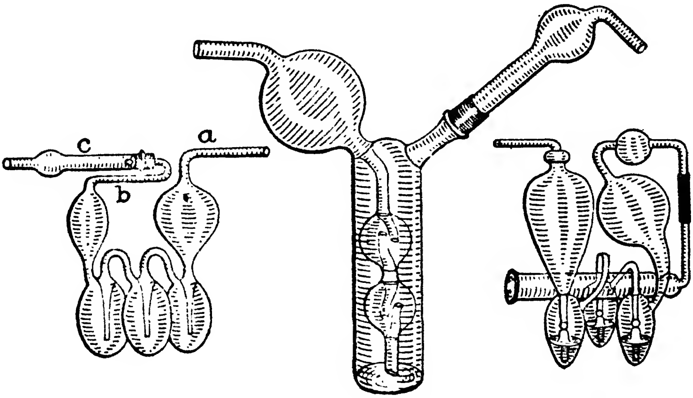


Fig. 39 Fig. 40 Fig. 41

The carbon dioxide is usually collected in potash bulbs or in soda-lime tubes.

Figs. 39–41 represent three of the commonest forms of potash bulbs. Fig. 39, Mohr's, is the common type; the three bulbs are three-fourths filled with a concentrated solution of potassium hydroxide (1 : 1·5). This is accomplished by dipping the tube *a* into the alkaline solution whilst the tube *b* is attached to a pump by means of a rubber connexion and a sufficient quantity of the liquid is gently sucked in. The end *b* is carefully cleaned and dried, and the side tube *c* attached after the joint has been very slightly greased. This side tube contains either granular calcium chloride or small pieces of solid potassium hydroxide kept in position by plugs of glass wool. The object is to retain moisture carried away from the potash solution as the gas bubbles through; the solid potash has

the further advantage of absorbing any carbon dioxide which escapes absorption in the bulbs. Fig. 41 represents Wetzel's modification of Mohr's apparatus. The advantage it possesses is that the gas bubbles are retained for a longer time in contact with the alkaline solution. This is effected by means of the funnel-shaped piece of glass in each bulb. The absorption is more efficient, and the combustion can be carried out in a shorter time than is required when the ordinary Mohr's bulbs are used. Fig. 40 represents Bender's potash bulbs, which are somewhat more convenient for weighing, as they stand upright.

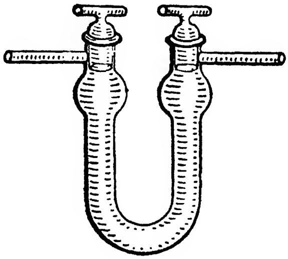


Fig. 42

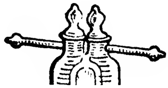


Fig. 43

At the present time there is a tendency to replace potash bulbs by soda-lime tubes. The usual form of tube is shown in fig. 42. Two tubes are used; the one nearer the combustion tube is filled with soda lime only, the second has the inner limb filled with soda lime, but the outer limb with granular calcium chloride. The tubes can be shut off from communication with the air by means of the cocks, which must be completely air-tight. The soda lime absorbs carbon dioxide much more readily than the potassium hydroxide solution, and the whole combustion can thus be conducted in a much shorter time and with far less risk of any of the gas not being absorbed.

The absorption tube shown in fig. 43 has a capacity of about 15–20 g. The left-hand compartment and the lower half of the right-hand compartment are filled with granular soda-lime and the remainder of the right-hand compartment with granular calcium chloride. With either potash bulbs or soda-lime tubes it is necessary to protect the free end from atmos-

pheric carbon dioxide and moisture during the combustion. This is accomplished by means of a straight tube filled with calcium chloride and soda-lime. Before weighing, all tubes should be wiped with a clean dry cloth. All ground joints should be greased with the smallest possible amount of vaseline, so that none of this is exposed; otherwise, when the tube is wiped, a portion of the exposed grease will be removed and a serious alteration in the weight of the tube will occur.

It must be remembered that if the tubes are weighed before the combustion, when filled with air, they must be weighed afterwards filled with the same gas; so that if the combustion has been conducted with oxygen it is necessary to replace this by dry air before reweighing. Any one of the tubes will be appreciably heavier when filled with oxygen than when filled with air.

If either potash bulbs or soda-lime tubes are employed it is necessary to refill them frequently; with the soda-lime tubes after every one or, at least, after two combustions.

Carrying out the Combustion.—After the combustion tube has been thoroughly dried, the end of the tube nearer the drying apparatus is allowed to cool. During this time the absorption vessels and the substance to be combusted can be weighed. If the substance is a solid it is weighed in a platinum or porcelain boat which has been previously ignited, allowed to cool in a desiccator, and weighed. Care should also be taken that the substance itself is quite dry. The amount required is small, as a rule about 0·2 g., and the boat and substance are kept in the desiccator until introduced into the tube. If the substance is not too readily volatile, the boat may be introduced into the combustion tube whilst still warm. This is accomplished by removing the stopper, withdrawing the oxidized copper coil by means of a glass rod with a hook at the end, pushing in the boat until it nearly touches the small coil *b* (fig. 35), and rapidly replacing the oxidized coil and the stopper. Before the boat is introduced it is advisable to attach the absorbing vessels to the front end of the tube, as shown in fig. 44. All joints should be tight and, if necessary, the rubber tubes should be wired on. A slow stream of dry air or oxygen, at the rate of about 2 bubbles per second, is passed through the tube. The regulation of this current is most easily made by means of a screw clip. One or two burners are lighted beneath the oxidized copper coil, and also gradu-

ally under the layer of granular copper oxide next to the boat. The lighting and regulation of the flames will vary considerably with the properties of the substance which is being combusted: the more volatile the compound the greater is the care required in turning on the burners; the whole operation must be conducted in such a manner that at no time is the evolution of the products of combustion rapid; if there is an indication that the substance is being volatilized too rapidly, one or more flames must be extinguished. The heating may also be accomplished by gradually lowering the fireclay tiles over the tube. Ultimately the portion of the

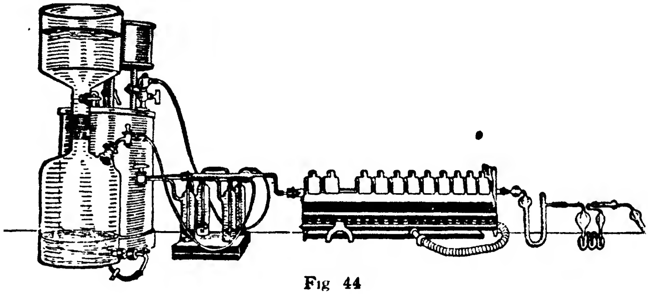


Fig 44

tube where the boat is contained is raised to a dull red heat; the front part of the tube should be at a dull red heat during the whole operation, but care should be taken that no part of the tube is raised to a bright red heat, as the glass will then soften and become distorted, and in all probability the gaseous pressure inside the tube will blow holes in the soft glass.

When an electrically heated furnace is used, the temperature can be regulated by gradually pushing the small furnace towards the portion of the tube where the substance is. When a gas furnace is employed and the current of air or oxygen is slow, drops of water occasionally collect at the back end of the combustion tube near the stopper. These can be driven forward by gently warming the tube by means of a small flame or by means of one of the hot tiles. With an electrically heated furnace this condensation does not occur. One object in placing an oxidized spiral behind the substance is in order to oxidize any volatile material which passes back.

Moisture also tends to collect near the stopper at the front

end of the tube, but if the temperature of this part of the tube is regulated carefully, the glass will be too hot for water to condense and yet not sufficiently hot to decompose the rubber stopper. To prevent the latter a shield of asbestos board may be used. If water does condense it can be driven over into the calcium chloride tube at the end of the experiment by gently heating this end when a more rapid current of oxygen is passed through the tube. The oxygen is continued until the gas issuing from the calcium chloride tube, used as a guard for the potash bulbs or soda-lime tubes, is capable of igniting a glowing splint. The oxygen can then be replaced by air and the absorption tubes removed, allowed to cool, and weighed.*

If it is wished to carry out a second combustion on the same day, the front part of the tube is kept hot and a straight calcium chloride tube is inserted in the front end whilst the back part of the tube is allowed to cool. A fresh amount of substance is weighed out, and fresh calcium chloride tube and potash bulbs are weighed and attached, and the combustion carried out as already described.

Modifications of the Combustion.—The method described above is the common process for the estimation of carbon and hydrogen when carbon and hydrogen or carbon, hydrogen, and oxygen alone are present in a solid. Various modifications have to be introduced when the substance is a liquid, or when other elements such as nitrogen, sulphur, or halogens are present.

Estimation of Carbon and Hydrogen in a Liquid.—If the liquid is practically non-volatile at the ordinary temperature, and is not hygroscopic, it may be weighed in the open boat, otherwise it is advisable to weigh it in a small tube closed at one end, and provided with a loosely fitting stopper made out of a piece of glass rod flattened at one end (fig. 45). This tube can be introduced into the combustion tube by placing it in the boat in a slightly sloping position, and then pushing both into the tube with the open end of the vessel towards the layer of copper oxide.

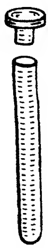


Fig. 45

Substances which are extremely volatile are usually introduced into small glass bulbs which have been

* The absorbing vessels should not be weighed too soon after the combustion, but should be allowed to stand for several hours, preferably in the balance case.

previously weighed. When the liquid has been introduced the bulb is sealed and reweighed. Before being introduced into the combustion tube the upper part of the neck is broken off and both parts placed in the boat.

Estimation of Carbon and Hydrogen in Presence of Nitrogen.—Certain nitrogen compounds, when combusted in the usual manner, yield higher oxides of nitrogen, which are absorbed either in the calcium chloride tube or in the potash bulbs and thus vitiate the results. The difficulty is readily overcome by placing a freshly reduced coil of copper gauze (some 10–15 cm. long) in the front part of the combustion tube in place of part of the granular cupric oxide. When the nitrogen oxides come in contact with the heated copper they are reduced to free nitrogen, which passes through the various absorbing vessels.

The simplest method of reducing the copper coil is to heat it strongly in the blowpipe flame in order to remove all organic matter, and to drop it while still hot into a large test tube of hard glass surrounded by a duster and containing a small amount (0·5–1·0 ml.) of methyl alcohol. The vapour of the methyl alcohol reduces the crust of cupric oxide on the coil, which should then have the characteristic colour of metallic copper. The coil is removed to a dry tube provided with a rubber stopper and glass tube which is attached to the pump. When a good vacuum has been reached, the tube and coil are heated in order to remove moisture and gases, the coil is allowed to cool under the diminished pressure and is then ready to be transferred to the combustion tube. During the combustion it is not advisable to pass air or oxygen through the tube, but to turn the stopcock and to pass the oxygen when the whole tube has been heated and when the burners under the reduced copper coil have been turned out.

N.B.—If the copper coil is reduced in a current of hydrogen gas, it is necessary to reheat it in some indifferent gas, e.g. carbon dioxide, as copper occludes hydrogen.

Certain polynitro-compounds are somewhat explosive when heated, and hence cannot be introduced in the ordinary manner in a small boat. The simplest method of preventing a too rapid decomposition is to use a large copper boat which will just pass into the tube. This is partly filled with thoroughly dry powdered cupric oxide. A weighed amount of the nitrogen compound is added and mixed to a certain

extent with the oxide by means of a thin glass rod. The mixture is finally covered with more dry copper oxide until the boat is three-fourths full, and the boat can then be placed in the combustion tube and the temperature gradually raised. The copper oxide with which the substance is mixed is dried by ignition in a copper or porcelain crucible and allowed to cool in a desiccator. With the exception of the copper boat the remainder of the tube is fitted up as for the determination of hydrogen and carbon when nitrogen is also present.

Estimation of Carbon and Hydrogen in the Presence of Halogens.—If the compound to be combusted contains a halogen, a copper halide will be formed. Most of these are volatile to a certain extent, and are also partially decomposed by oxygen at high temperatures, yielding free halogen. The passage of this halogen into the absorbing tubes can be prevented by placing a coil of silver gauze in the front part of the tube and keeping this at a moderate temperature, when the halogens will be retained in the form of silver halide. It is usual, however, to replace the copper oxide in the combustion tube by lead chromate,* which has been fused and broken up into small lumps. Under these circumstances lead halides are formed. These are less volatile and more stable than the corresponding copper compound, and there is thus less risk of halogen finding its way into the absorbing vessels. As a precaution it is advisable that the lead chromate in the extreme front part of the tube should not be heated too strongly, and that a silver coil should also be used.

Estimation of Carbon and Hydrogen in the Presence of Sulphur.—The compound is oxidized in a hard-glass tube filled with lead chromate, as, if cupric oxide were used, the cupric sulphate would be decomposed and sulphur dioxide would escape and be collected in the absorbing vessels. Plumbous sulphate is more stable, but is decomposed to a certain extent at high temperatures, so that it is advisable to have the front portion of the tube at a somewhat lower temperature than the middle portion. After the combustion of a sulphur compound it is always advisable to test the water that condenses in the bulb of the calcium chloride tube and make sure that it is free from sulphurous or sulphuric acid.

* Aliphatic halogen derivatives give excellent results with lead chromate, but a few aromatic compounds rich in bromine yield low results for carbon, owing to the fact that part of the carbon is retained by the fused lead bromide.

Compounds containing alkali or alkali-earth metals are mixed with pure potassium dichromate or lead chromate and then combusted, as otherwise they retain a certain amount of carbon dioxide in the form of the metallic carbonate. The use of lead chromate is far less convenient than cupric oxide as it readily attacks the glass of the combustion tube and renders it liable to crack. With a good hard-glass tube it is easy to conduct twelve or more combustions in the same tube when cupric oxide is used; but with chromate the tube often cracks after using once or twice. If the tube is heated too strongly the chromate fuses, and when it solidifies again is certain to crack the tube.

When sulphur is present, the same lead chromate should not be used more than three or four times.

B. Estimation of Nitrogen

Nitrogen in organic compounds can be estimated either as gaseous nitrogen or in the form of ammonia. In the former case the compound is oxidized as in the determination of carbon and hydrogen, and the liberated nitrogen measured in a *nitrometer* (Dumas' method). In the latter case the compound is heated with concentrated sulphuric acid, whereby all nitrogen is converted into ammonium sulphate, which is then decomposed by excess of concentrated alkali and the liberated ammonia absorbed in a known volume of standard acid (Kjeldahl method).

1. **Dumas' Method.**—The process commonly made use of for scientific purposes is the Dumas method, which consists in heating the substance with cupric oxide, reducing any oxides of nitrogen by means of copper coils, and measuring the volume of nitrogen produced. The air within the tube must be removed (*a*) either by means of a good mercury pump, or (*b*) by replacement by some other gas, such as carbon dioxide, which can be readily absorbed by a suitable solvent. The latter method is generally used, as it is somewhat simpler, but in either case the risk is that certain amounts of oxides of nitrogen will be formed, and will not be completely reduced. If nitrous oxide, N_2O, is present it does not interfere with the determination, as the volume is equal to the volume of nitrogen to which it would give rise; if, however, nitric oxide, NO,

is present the percentage of nitrogen comes too high, as the volume of this oxide is double the volume of the nitrogen which would be formed by its reduction. Numerous authorities have drawn attention to the presence of small amounts of nitric oxide in the gases collected; but T. Gray, who has made a number of experiments on the estimation of nitrogen by Dumas' method, using carbon dioxide as the displacing gas, claims that nitrogen free from nitric oxide is obtained if the following conditions are fulfilled: The copper coil in the front part of the tube should be 5 in. long, should be tightly rolled, and should just fit into the tube; the coil should be strongly heated, and the current of carbon dioxide should be stopped during the actual combustion.

Generating the Carbon Dioxide.—The carbon dioxide may be generated within the combustion tube (see fig. 46), and then a tube closed at one end is used and the source of the carbon dioxide is magnesite ($MgCO_3$) in the form of lumps about the size of peas. The simplest method is to generate the carbon dioxide in a Kipp's apparatus from marble and hydrochloric acid. In this case it is essential to test the gas before it is used, in order to make sure that it is free from air. To facilitate the removal of air it is an advantage to boil the marble with water before it is introduced into the generator.*

The Combustion Tube.—If a closed tube is used it is filled as shown in fig. 46. The tube is of hard glass, closed at one end. The cupric oxide should be ignited in order to remove all organic nitrogenous matter, but it is not necessary to protect it from atmospheric moisture. The simplest method of igniting the oxide is in a large nickel or copper crucible. The coil in the front part of the tube is reduced in the manner described on p. 52, but it is not necessary to dry it in a vacuum. The weight of substance taken should be sufficient to yield at least 20 ml. of nitrogen at atmospheric temperature and pressure, but not sufficient to yield more gas than can be collected in the nitrometer employed, viz. 50 ml. The known weight of substance and the powdered cupric oxide are mixed in a small mortar, and introduced into the tube by means of a glass or metal funnel, the mortar being rinsed out several times with small amounts of powdered oxide.

If a tube open at both ends is used, it is filled as shown in

* For further precautions see "Estimation of Nitrogen by Microchemical Method".

fig. 47. The given weight of substance may be mixed with the powdered cupric oxide and introduced directly into the tube, or the mixture may be placed in a large copper or porcelain boat. In either case it is not necessary to remove the long layer

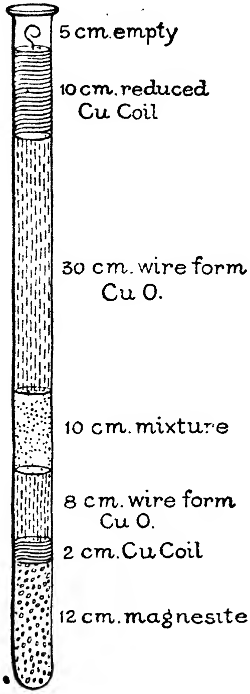


Fig. 46

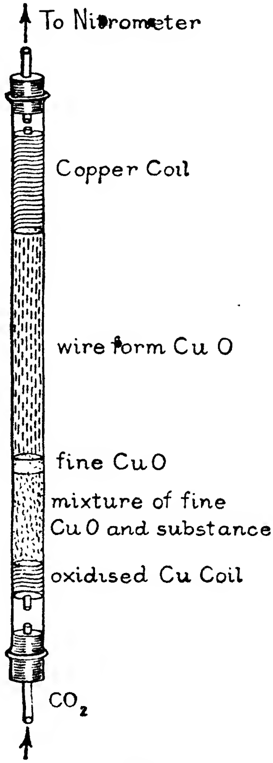


Fig. 47

of wire-form cupric oxide when a second determination is to be made; all that is necessary is to remove the powdered oxide, to ignite this, and to pass a current of oxygen over the heated layer of wire-form oxide.

For most purposes the open tube method is the more convenient, and is absolutely essential if the substance to be analysed is readily decomposed, as when the closed tube is

used there is great risk that the part of the tube in contact with the mixture of substance and copper oxide may become heated too strongly by the burners under the magnesite. When the tube has been placed in the furnace the first essential is to remove the air in the tube. This is accomplished by passing a fairly rapid stream of carbon dioxide (from the heated magnesite or from the Kipp) through the tube *before* the measuring vessel (nitrometer) is attached. If this is at-

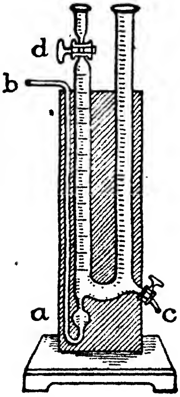


Fig. 48

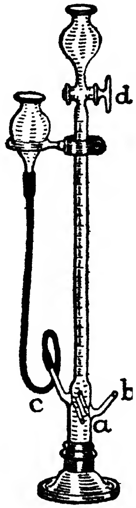


Fig. 49

tempted after the attachment of the nitrometer it will be found to take a much longer time. When most of the air has been displaced, the nitrometer (figs. 48 and 49) is attached, and the burners may be lit beneath the copper coil and part of the layer of cupric oxide; the issuing gas is tested from time to time by filling the measuring tube with the potassium hydroxide solution, and noticing whether all the gas bubbles are absorbed. When no more air is present, the measuring tube is filled with the alkali. The burners beneath the tube are gradually lighted until the mixture itself is heated, when the front part of the tube is at a dull red heat. The manner in which the flames are ignited, raised, or lowered must be

suited to the individual substance. After the stream of carbon dioxide has been turned off, the bubbles of gas should pass in a regular stream, about 2 per second, into the nitrometer. In no case must a great rush of gas be allowed. After the combustion is completed, and the whole length of the combustion tube has been raised to a dull red heat, the carbon dioxide is again turned on, and the products of combustion swept out gradually into the nitrometer. When all the gas issuing is absorbed the tube is clamped and the nitrometer removed. The whole combustion takes on the average about an hour and a half.

The Nitrometer.—Various forms of apparatus are used for collecting and measuring the nitrogen evolved. Fig. 48 represents the Schwarz *nitrometer* and fig. 49 the Schiff *nitrometer*. The liquid used in both cases is a concentrated solution of potassium hydroxide (1 : 2), and a mercury trap at *a* is used in order to prevent the alkali rushing back into the combustion tube owing to the rapid absorption of carbon dioxide.

In the Schwarz nitrometer the measuring tube is filled by opening the stopcock *d* after the apparatus has been attached to the combustion tube at *b*, and pouring in the liquid until the two tubes are full, then closing the stopcock and running the liquid out of the side tube *c*. In the Schiff nitrometer the combustion tube is attached to the side tube *b*, and the measuring tube is filled by raising the reservoir attached to *c* whilst the stopcock *d* is open. The cock is then closed and the reservoir lowered.

Points to be borne in mind are: (1) Do not have the nitrometer attached whilst the air is being displaced, and if, after testing, air is still found to be present, remove the alkali from the measuring vessel whilst more carbon dioxide is passed through, as otherwise the alkali will be used up and will not be effective when the actual combustion is in progress; (2) do not use sodium hydroxide solution instead of potassium hydroxide, as the carbonate will crystallize out; (3) remove the alkali and wash the nitrometer thoroughly after use, as otherwise the stopcocks will stick; (4) tilt the furnace so that the front part of the tube is at a lower level than the back portion. By this means any water which condenses in the front end of the tube cannot run back on to the hot glass and crack the tube.

Calculation.—The volume *v* ml. of nitrogen measured at

p mm. pressure and $t°$ C. is reduced to normal temperature and pressure, care being taken that the tension of the caustic potash solution (Table XX, Appendix) is subtracted from the barometric pressure, or the gas can be transferred from the nitrometer to a graduated tube placed in a tall cylinder of water. The temperature is then the temperature of the water, and the pressure the barometric pressure minus the tension of aqueous vapour at that temperature (Table XXI, Appendix). The percentage of nitrogen is then—

$$\frac{v(p - q)0{\cdot}12505 \times 273}{760(273 + t)w},$$

where q is the tension of aqueous vapour at $t°$, w = weight of substance taken, and ·0012505 is the weight of 1 ml. of nitrogen at normal temperature and pressure.

The calculation can be facilitated by the use of tables which give the weight of pure nitrogen in milligrammes contained in 1 ml. of moist nitrogen under different conditions of temperature and pressure.

2. **Kjeldahl Method.***—The method consists in heating the substance with concentrated sulphuric acid, or a mixture of sulphuric acid and potassium sulphate, until the liquid is clear and colourless. The carbon becomes oxidized to carbon dioxide and the nitrogen converted into ammonia (ammonium sulphate). The amount of ammonia formed can be determined by making the liquid strongly alkaline, distilling off the ammonia, and collecting in a known volume of standard acid. The method gives good results with the following groups of organic compounds: Amines, ammonium compounds, pyridine and quinoline derivatives, alkaloids, proteins, and related compounds. It is the method usually employed for estimating nitrogen in feeding-stuffs, organized tissues, animal fluids, &c. It should be remembered that the following groups of compounds do not yield quantitative results unless subjected to a preliminary treatment: Nitro, nitroso, azo, hydrazo, diazonium compounds, and probably cyanogen derivatives and platinichlorides of bases.

From 0·5–1·0 g. of the substance is heated by means of a Bunsen burner in a 300 ml. Kjeldahl flask (fig. 50), made of resistance glass, with 20–30 ml. of a mixture of sulphuric

* Z. A. 1883, 366.

acid * (3 parts) and potassium sulphate (1 part). As sulphur dioxide is evolved in large quantity the operation should be conducted in a good fume-cupboard or in an apparatus so arranged that the sulphur dioxide can be absorbed (Vogtherr).

In the Vogtherr apparatus (fig. 51) the flask (500 ml.) is fitted with a ground-in head which carries a tube bent twice at right angles. The free end of this tube is attached by means of a rubber stopper to the pear-shaped absorbing tube, the lower end of which dips into the absorbing liquid contained

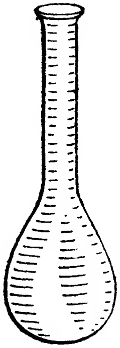


Fig. 50

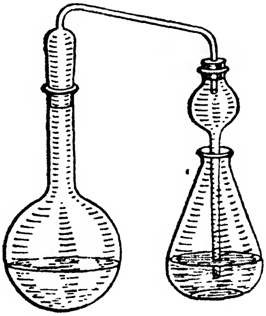


Fig. 51

in a flask. As long as sulphur dioxide is being evolved, sodium hydroxide solution is placed in the absorbing flask. When the evolution of sulphur dioxide ceases, the small flask is lowered so that the end of the absorbing tube is just above the surface of the alkali, and the contents of the flask are further heated until colourless. The head and absorbing tube are removed and well washed when the flask is cold, the sulphuric acid is diluted with 100 ml. of distilled water, and then some 200 ml. of a 15 per cent solution of sodium hydroxide and a little zinc dust run in, the head and absorbing tube replaced, the liquid boiled, and the ammonia collected in an excess of standard acid contained in the absorbing vessel. If Vogtherr's apparatus is not used, it is customary, as soon as the liquid in the Kjeldahl flask is colourless, to allow it to

* All the materials used in the Kjeldahl estimation should be previously tested for nitrogen. The simplest method is to perform a blank estimation with a substance free from nitrogen (e.g. cane sugar), using known quantities of acid, potassium sulphate, and sodium hydroxide, and if nitrogen is found, to deduct the amount from each subsequent determination.

cool, then to pour it into a larger flask and to add an excess of 20 per cent sodium hydroxide solution, care being taken that the acid and alkali are not thoroughly mixed until the absorbing vessel is attached.

The alkaline liquid is then boiled, or steam is blown through, and the escaping ammonia collected in a known volume of standard acid. It is customary to introduce some form of safety tube (fig. 52) between the distillation flask and the vessel containing the standard acid. The object of such a tube is to prevent particles of the alkaline solution from being carried over.

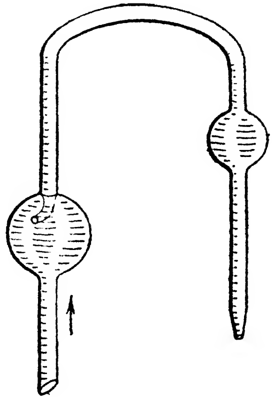


Fig. 52

The addition of one or two grams of zinc dust to the contents of the flask prevents the alkaline liquid from bumping during the distillation. If a Liebig condenser is used, the time required for the whole of the ammonia to be driven over is somewhat considerable, owing to the ammonia dissolving in the water which is deposited in the condenser tube. Lassar-Cohn recommends distilling for fifteen minutes, using a water condenser, then running the water out of the condenser so that the condensing tube becomes hot, and continuing the distillation for a further five minutes or until the contents of the receiver become hot.

Each millilitre of 0·1 N. acid neutralized by the ammonia corresponds with 0·0014 g. of nitrogen in the given weight of substance used.

C. Estimation of Halogens

Various methods are used for determining the percentage of halogen in an organic compound. The Carius method is generally used, but the method introduced by Stepanow,* and further described by Bacon,† is considerably simpler in practice, and yields concordant results if the essential details stated below are observed.

* B. 1906, 39, 4056. † J. A. C. S. 1909, 31, 49.

1. **Stepanow's Method.**—0·2–0·3 g. (= a) of the substance to be analysed is introduced into a flask and a volume of 98 per cent ethyl alcohol added. (Volume of alcohol required is 156a ml. if chlorine is present, 68a ml. if bromine, and 44a ml. if iodine is present.) The flask is attached to a reflux condenser and the solution boiled while a quantity of clean metallic sodium (19·5a g. if chlorine is present, 8·5a g. if bromine, and 5·5a g. if iodine is present) is added in small pieces through the condenser tube. This addition should extend over *at least* 30 min., and the mixture should then be boiled for an hour. After cooling to 50–60°, water is added through the condenser tube, then nitric acid in slight excess and a known volume of standard silver nitrate solution. After filtering off the silver halide, the excess of silver nitrate in the filtrate is titrated with a standard solution of ammonium thiocyanate (Volhard's method, cf. Treadwell and Hall, Quantitative Analysis). Hence the percentage of halogen in the compound may be calculated.

As an alternative, or when the solution is coloured, the precipitate of silver halide should be weighed, but in this case it is advisable to remove the alcohol by distillation before the addition of nitric acid, as otherwise explosive silver fulminate may be formed.

The method renders the estimation of two halogens in the same compound a comparatively simple operation. The reduction is effected as already described. The acidified aqueous liquid is mixed with an excess of standard silver nitrate solution and the precipitated silver halides removed, washed, and weighed. In the filtrate and washings the excess of silver nitrate is determined by titration with standard ammonium thiocyanate.

From the weight of silver required for complete precipitation and the weight of the mixed silver halides precipitated the amount of the two individual halides can be calculated. Example:

If a = weight of Ag, and b = weight of mixed AgCl and AgBr.

Then, assuming all b were AgCl, calculate wt. of Ag = c,
and ,, ,, AgBr ,, ,, Ag = d.

Then $\frac{c-a}{c-d}100 = x$ = percentage of AgBr in mixture of AgCl and AgBr, and $100 - x$ = per cent of AgCl.

From these numbers the percentage of Cl and Br in the original substance can be calculated.

2. **Carius' Method.**—The method consists in heating the substance under pressure with fuming nitric acid and silver nitrate, and then estimating the amount of silver halide formed either volumetrically (Volhard's method) or gravimetrically using a sintered crucible.

The estimation is carried out in a sealed tube made of special glass. Such tubes rarely burst if properly sealed, and may be used a number of times. Tubes made of ordinary combustion glass or thick-walled tubes of soft glass should not be used, as they burst more readily and can only be used once or twice. A tube, closed at one end and of a length suitable to fill the bomb furnace (fig. 54), is selected and thoroughly cleaned and dried; in the tube is placed an excess of silver nitrate crystals (in most cases about 0·5 g. is ample) and not more than 20 drops of pure * fuming nitric acid of sp. gr. 1·5. A common mistake is to use too large a quantity of acid and thus increase the risk of bursting the tube. The acid should be run in by means of a long thistle funnel, and this should be carefully removed so that no drops of acid come in contact with the upper part of the tube.

The substance (not more than 0·2 g.) is weighed in a small clean tube closed at one end and about 7 cm. long and 6–8 mm. diameter. If the substance is comparatively volatile, a loosely fitting glass stopper made from a bit of glass rod can be placed in the open end of the weighing tube (cf. fig. 45). This tube is then introduced into the bomb tube in such a manner that it slides slowly down the inner surface until it comes in contact with the part moistened with the acid. It is not advisable to let it drop to the bottom, as the acid is then liable to creep into the weighing tube and decompose the substance before the bomb tube is sealed. The upper end of the tube can then be sealed off as follows: The end is gradually heated in a small smoky flame of a blowpipe whilst the tube is held at an angle of about 45° and slowly turned in the hand, so that the whole upper end becomes evenly heated; when hot, the blowpipe flame should be used, and when the glass is soft a piece of hot glass rod is fused on. The flame is then directed a little lower down on the tube, while it is still slowly turned in the hand. As soon as it is

* It is obvious that all the reagents employed should be free from halogens. As nitric acid often contains hydrochloric acid it should be tested before being used.

sufficiently soft it is drawn out into a capillary which can be cut by a file some 3 or 4 in. above the shoulder. The shoulder and capillary are far too thin to withstand pressure, and require thickening. This is accomplished by heating the shoulder in the blowpipe flame, whilst the tube is turned gradually in the left hand and the capillary very gently supported by two fingers of the right hand. If the capillary is held tightly the glass will twist and become distorted. As soon as the walls have thickened considerably and have almost met, the shoulder can be drawn out to form a thick capillary which can then be sealed off in such a way that the end of the tube has the appearance represented in fig. 53.

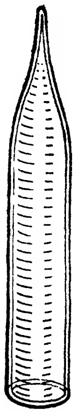


Fig. 53

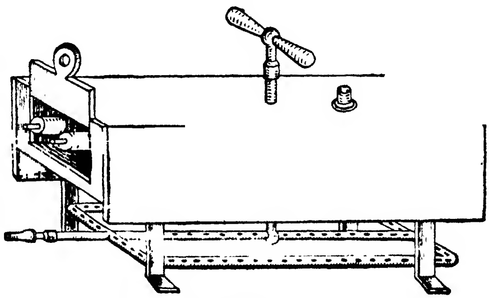


Fig. 54

The sealed end is held in the smoky flame until it is covered with a deposit of soot, and then allowed to cool. The tube is ready for heating in the bomb furnace (fig. 54) after it has been wrapped in asbestos paper and placed in an iron protecting tube. The flames are lit under the bomb furnace, and the temperature fairly rapidly raised to 320–340° * by adjusting the burners, and kept at that temperature for several hours. The tube is allowed to cool, and opened the following morning. The tubes should never be opened whilst hot, and should not be touched with the naked hand even when cold, as there is a risk of explosion. To open the tube the capillary end is raised

* Many aliphatic halogen derivatives are completely destroyed at much lower temperatures, viz. 250°. For temperatures above 300° a thermometer filled with nitrogen under pressure should be used, as otherwise the mercury thread breaks at the high temperature.

from the protecting iron tube and very gently warmed in order to drive out drops of acid which may have condensed into the capillary, which is then heated in a Bunsen flame until the glass softens and the compressed gases escape by a hole which they themselves blow in the soft glass. When the pressure in the tube has been completely released, as shown by holding a flame near the hole, the upper conical part of the tube is broken off. This is readily accomplished by making a fairly deep file mark at the requisite point, and then heating this mark by means of a red-hot glass rod. The tube cracks at the mark, and by gradually carrying the hot rod round the circumference of the tube the crack may be extended right round, when the upper portion will fall away. The contents of the tube are removed into a beaker by means of distilled water, the small tube is thoroughly washed, and all traces of silver halide removed from both tubes into the beaker, which is then heated until the precipitate has settled to the bottom and the liquid is quite clear. If the silver halide is at all lumpy it should be pressed out with a glass rod, as it is liable to retain small amounts of silver nitrate and nitrite. The precipitate is removed on to a quantitative filter paper, or preferably a sintered crucible, thoroughly washed with distilled water until the filtrate yields no precipitate with dilute hydrochloric acid, and the operation completed in the usual manner for the estimation of silver halides. After the analysis is completed it is always advisable to examine the silver salt, in order to make sure that it does not contain splinters of glass. This may be done by adding potassium cyanide solution to the crucible, allowing to stand for some time, then sucking the solution through by means of the pump, thoroughly washing first with potassium cyanide solution and finally with water, drying, and reweighing. Any increase in weight of the crucible must be due to glass, and this weight can be subtracted from the weight of silver halide previously found.

If a known weight of silver nitrate is placed in the Carius tube, then it is possible to estimate the percentage of halogen by determining by a volumetric process such as Volhard's the amount of silver nitrate left after the tube has been heated.

When estimating iodine the precipitate must be boiled with the liquid for 3 hr., after crushing with a glass rod, as a sparingly soluble compound of silver iodide and nitrate is formed.

D. Estimation of Sulphur

1. **Carius' Method.**—The substance is heated with fuming nitric acid in a sealed tube, as in the Carius method for estimating halogens. After the tube has been opened the sulphuric acid formed is estimated as *barium sulphate*. It is advisable to remove the nitric acid before the precipitation is carried out, as it is found that barium sulphate precipitated in the presence of the nitrate carries down with it small amounts of nitrate which cannot be removed by subsequent washing with water. In order to remove the nitric acid the contents of the bomb tube are rinsed into a porcelain dish, hydrochloric acid is added, and the solution evaporated on the steam bath. The solution is then diluted to about 400 ml. boiled, and the sulphate precipitated by the addition of a *slight excess* * of boiling barium chloride solution. The precipitate is removed to a filter paper, washed with hot water until a sample of the washings no longer produces a turbidity with dilute sulphuric acid, dried, and weighed

2. **Messenger's Method** is a rapid one which can be used when the substance is non-volatile. The oxidizing agent is alkaline permanganate and the sulphur is finally estimated as sulphate by precipitation with barium chloride solution. A known weight of substance is added to a flask fitted with an air condenser (ground-in if possible) and containing 2 g. of powdered potassium permanganate and 0·5 g. of pure potassium hydroxide. 25 ml. of water are added through the condenser, the whole gently boiled for 2–3 hr. and then cooled. The excess permanganate is removed by adding hydrochloric acid until no more gas escapes. The flask is heated, and the clear liquid transferred to a beaker and the sulphuric acid estimated.

Potassium dichromate and hydrochloric acid can also be used for the oxidation, the excess of dichromate being destroyed by the careful addition of alcohol.

3. **Sodium Peroxide Method.**—When the sulphur compound is not volatile in the presence of alkali, e.g. the salts of sulphonic acids, the following process is recommended. The

* A large excess of barium chloride should be avoided, as the sulphate tends to retain small amounts of the chloride from concentrated solutions, and this chloride cannot be removed by washing. For details, see *Treadwell and Hall,* Quant. Analysis.

substance (0·2–0·8 g.) is mixed in a nickel vessel with 10 g. of a mixture of equal parts of sodium peroxide and anhydrous sodium carbonate and heated over a small flame until a clear melt is obtained (about 20 min.). After cooling, the melt is dissolved in water, the solution acidified with hydrochloric acid, and the sulphur precipitated and weighed as barium sulphate.

E. Estimation of Phosphorus and Arsenic

Estimation of Phosphorus.—The substance is oxidized to phosphoric acid by one of a variety of oxidizing agents and subsequently precipitated and weighed as magnesium pyrophosphate. The oxidation may be carried out by the Carius method (as for sulphur), but the following is also reliable:

*Messenger's Method.** 0·3–0·4 g. of substance is weighed in a small tube and placed in a reflux apparatus (preferably with ground-in connexions) with 4–5 g. of chromic anhydride. 10 ml. of sulphuric acid (2 parts concentrated acid to 1 part of water) are added through the condenser and the mixture boiled for an hour. 10 ml. more acid are then added and the boiling continued for another hour.

The resulting solution is treated with 3–4 g. of solid ammonium nitrate and 50 ml. of ammonium molybdate solution (cf. Treadwell and Hall) and warmed on a water bath for 2 hr. The green solution is poured off from the precipitate through a filter, and the precipitate washed by decantation several times with a solution of ammonium nitrate (20 g. in 100 ml. water) which has been acidified with dilute nitric acid.

The precipitate is dissolved in 40 ml. of dilute ammonia, the clear solution treated with 4–5 drops of a saturated solution of citric acid (to retain traces of chromium compounds in solution), the phosphate precipitated as magnesium ammonium phosphate by addition of magnesia mixture, filtered and weighed as magnesium pyrophosphate.

Estimation of Arsenic.—Compounds containing arsenic are generally oxidized (or reduced) to arsenites which may then be estimated:

1. By reduction to arsine as in *Marsh's method*. In *Evans'*†

* B. 1888, 2916. † Analyst, 1920, 45, 8.

method the arsine is passed over heated copper on which the arsenic is deposited quantitatively, the increase in weight of the copper being a measure of the amount of arsenic present.

2. By titration with a standard iodine solution. *Ewins' Method.** About 0·2 g. substance is placed in a Kjeldahl flask of 300 ml. capacity with 10 g. potassium sulphate and about 0·2 g. of starch. 20 ml. of concentrated sulphuric acid are cautiously added, and the flask heated on a wire gauze over a Bunsen flame. When frothing occurs the flame is temporarily removed, treatment being continued until the liquid in the flask becomes colourless or of a pale yellow tint. The oxidation is usually complete in about 4 hr.

After cooling, the product is washed into a flat-bottomed flask (350 ml.) and made just alkaline to litmus paper by addition of a strong solution of sodium hydroxide (10 N.) gradually from a burette. After cooling again to 30–40° a few drops of concentrated sulphuric acid are added until the solution is again acid. A saturated solution of sodium hydrogen carbonate is next run in from a burette until the solution becomes distinctly alkaline and an excess of 10–15 ml. of the reagent is present.

Starch solution (2 ml. of a 1 per cent solution) is now added and the arsenite present titrated with 0·05 N. iodine solution until a permanent blue colour is obtained. 1·0 ml. of the iodine solution ≡ 0·001875 g. arsenic.

F. Estimation of Metallic Radicals

The estimation of **platinum, gold,** or **silver** is readily effected by heating a known weight of the salt, first gently and then more strongly, in a porcelain crucible until all the organic matter has been driven off and a clean residue of the metal is left. The precaution necessary for accurate results is to regulate the heating so that no violent reaction accompanied by spurting occurs.

Many of the heavy metals, such as **lead, copper, bismuth,** &c., can be precipitated from solutions of their salts by sulphuretted hydrogen. **Copper** may also be determined by igniting the salt to constant weight with continual access of air, and weighing the residue of oxide (Exp. 77).

* J. C. S. 1916, 1355.

Calcium is estimated by igniting a known weight of the salt and weighing as oxide. The complete removal of carbon and elimination of carbon dioxide requires some time, and the ignition and weighing should be repeated until the weight is constant.

Barium is estimated by precipitation as barium sulphate by the addition of hot dilute sulphuric acid to a boiling solution of the salt in water or dilute hydrochloric acid. The precipitate is collected in the ordinary manner or in a sintered crucible, washed, dried, and weighed.

The ammonia of an **ammonium** salt may be estimated in the usual manner by boiling a known weight of the salt with excess of potassium hydroxide solution, receiving the evolved ammonia in a known volume of standard acid, and estimating the excess of acid left by titration with standard alkali, using methyl orange as indicator.

The **sodium, potassium, calcium,** and **barium** radicals may be estimated by heating weighed quantities of the salts with concentrated sulphuric acid, preferably in a platinum crucible, and weighing as sulphate. This estimation requires care in order to avoid loss by the creeping of the mixture. The simplest method is to add a slight excess of sulphuric acid, to heat the crucible from above with a Bunsen flame, and after the sulphuric acid has been removed to add a small pellet of ammonium carbonate in order to transform any acid sulphate completely to the normal sulphate. The heating is then continued to constant weight.

Mercury.—About 0·4 g. of the mercury compound is boiled in a reflux apparatus with about 20 ml. of strong hydrochloric acid with gradual addition of crystals of potassium chlorate, until the substance goes entirely into solution or is converted into an oil. The flask is then fitted with a two-holed stopper carrying tubes, one of which dips into the liquid, the other being connected to a suction pump, and a current of air is drawn through until any chlorine gas remaining in solution has been removed. The mercury (present as mercuric chloride) is then precipitated by passing hydrogen sulphide through the solution, filtered through a Gooch or sintered crucible, dried at 100°, and weighed as mercuric sulphide.

VI. QUANTITATIVE ORGANIC MICROANALYSIS

A. Introduction

Methods of quantitative organic analysis requiring only a few milligrams of material for a determination have been worked out, mainly by Pregl.* The degree of accuracy is satisfactory if the weighings and analyses are carried out under carefully controlled conditions.

In order to obtain weighings of sufficient accuracy a balance of high sensitivity is required. Various types of *microchemical balance* are available, one of which, made by Oertling Ltd., is shown in fig. 55 (frontispiece). A student should be introduced to such an instrument by a competent instructor and should, first of all, study the maker's description of the particular type with care. When all precautions are observed, readings of weights down to thousandths of a milligram can be found by the method of swings.

In general it is unnecessary to use weights when weighing out samples for analysis, since the amount of material required usually lies between 3 and 5 mg. The vessel in which the substance is to be weighed is placed on the left-hand pan of the balance, while on the right-hand pan is placed a counterpoise, the weight of which has been adjusted so that it balances the empty vessel with the rider near the zero of the rider-scale. The weighing out of the sample for analysis then merely involves a movement of the rider. Small weighing tubes and platinum boats may be counterpoised with aluminium wire or with weights.

It is important to observe the following general precautions. The rider should sit vertically on the beam, and sideways swinging of the pans should be eliminated before releasing the beam. The temperature of the air inside the balance case must be kept equal to that of the room, and as nearly constant as possible. Weighing must be carried out as quickly as possible, since warmth from the experimenter may cause unknown changes in the zero during weighing. It is essential to avoid inequalities of temperature within the balance case. The hand should not be placed inside or near the case more than is absolutely

* *H. Roth*, "Pregl's Quantitative Organic Analysis" (translated by Daw), London, 1937; *Belcher*, R. Inst. Chem. Lecture, 1946.

necessary, all objects to be placed on the pans being handled with long, pointed forceps. The front door of the balance is only opened when it is required to clean the balance, and manipulation of objects and weights should be carried out using the side doors only. Pieces of apparatus which are used in weighing, particularly if made of glass, e.g. counterpoises and weighing tubes, should be kept inside the balance case so far as is possible. It is necessary carefully to prepare the surfaces of the objects to be weighed before a weighing and to standardize this preparation as completely as possible. Platinum boats are cleaned by boiling in dilute nitric acid, the acid being drained off and the boat heated to glowing in the Bunsen flame. The boat is held for this purpose on a hook of platinum wire sealed into a glass handle. After cooling on a copper block under a dust cover for a few minutes the boat is ready to be weighed. Glass-ware is first wiped carefully with a slightly moist fine chamois leather, then with a piece of dry leather, and left outside the balance case but near it for ten or fifteen minutes before being placed on the pan. The wiping should be done as quickly as possible to avoid warming the glass. In order to obtain satisfactory results when weighing glass-ware, it is necessary to prepare the surface in precisely the same way before each weighing. For the larger pieces of glass-ware the counterpoises used should be of nearly the same surface area as the vessel to be weighed. They may conveniently be small flasks containing a suitable quantity of lead shot. Before carrying out any weighing the object to be weighed is left for five minutes on the pan with the doors of the balance open in order to ensure equilibrium between inside and outside air. The zero point and sensitivity should be determined after each weighing. Great care must be taken not to injure the very finely ground knife-edges and planes by jarring the balance in any way.

B. Determination of Carbon and Hydrogen *

The principle of the microanalytical determination of carbon and hydrogen is the same as that of the large-scale method, viz. quantitative combustion of a known amount of material, with subsequent absorption and weighing of the water and carbon dioxide produced.

* *Pregl*, loc. cit.

Apparatus.—Pregl recommends a combustion tube of hard glass, at least 40 cm. long, and of external diameter about 1 cm., narrowing to a neck 2 cm. long and about 3 mm. external diameter at the end to be attached to the absorption tubes. The other end of the tube is closed by a stopper, removal of which allows the introduction of the boat containing the material to be analysed. Near this end is a capillary side tube through which air or oxygen enters the combustion tube. The form and filling of the tube are shown in fig. 56. Pregl's "universal" filling, suitable for substances containing halogens, sulphur, nitrogen or mercury, is as follows:

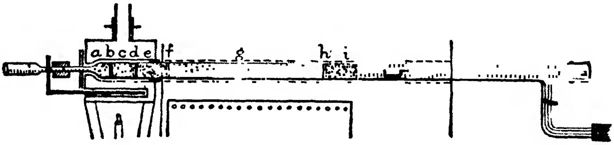


Fig. 56

(*a*) small wad of silver wool, length 10 mm.;
(*b*) small wad of asbestos, length 2 mm.;
(*c*) granulated lead peroxide, length 20 mm., absorbs oxides of nitrogen;
(*d*) three plugs of asbestos, total length 7 mm., for pressure regulation;
(*e*) layer of silver wool, length 30 mm., absorbs halogens;
(*f*) thin wad of asbestos, length 2 mm.;
(*g*) mixture of CuO and $PbCrO_4$, length 140 mm. $PbCrO_4$ absorbs sulphur;
(*h*) thin wad of asbestos, length 2 mm.;
(*i*) silver wool, length 30 mm., absorbs halogens.

Such a filling may be used for two or three hundred analyses unless several combustions of substances containing halogens are undertaken, when it is necessary to replace the silver wool nearest the boat after about twelve determinations. The apparatus is set out as shown in fig. 57. The combustion tube is supported on a stand so that the portion containing the lead peroxide is inside a heating mortar, shown in section in fig. 56. The mortar contains boiling decalin or *p*-cymene, which keeps the peroxide at a constant temperature to ensure a constant water content. The remaining portion of the filled tube is wrapped in wire gauze and is heated by a long burner, a tunnel of wire

gauze being placed over the tube. In the region of the boat the tube is heated with a Bunsen burner and a small roll of gauze is used to protect the part of the tube being heated. Air from a bottle previously filled with fresh air from outside the laboratory, and oxygen from a cylinder, enter the apparatus through pressure regulators, one of which is shown on the right of fig. 57. The regulator consists of two concentric glass tubes sealed together at the top, with their bottom ends dipping into water in an outer vessel open to the air. The gas enters through the inner tube and leaves through a side tube at the top of the outer tube, under a constant head of water (equal

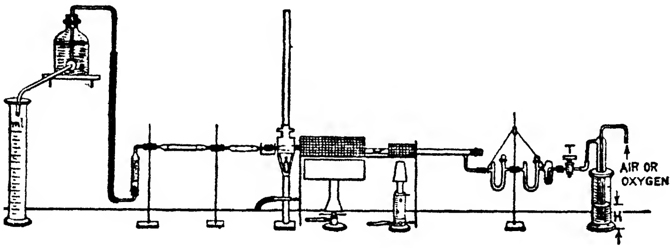


Fig. 57

to H in fig. 57). Any gas in excess of that required to maintain this head merely escapes to the outside air. Pressure regulation is necessary to ensure passage of gas through the apparatus at a rate sufficient to prevent striking back and yet to allow long enough contact of the organic material with the tube filling. By means of the three-way cock T either air or oxygen may be admitted to the combustion tube through the small bubble-counter which contains 50 per cent caustic potash solution. The bubbler is attached to a U-tube filled with glass wool mixed with phosphorus pentoxide, and this to a second U-tube containing " ascarite ", a special absorbent for carbon dioxide. The rubber tubing connecting the gas-holders to the bubbler must be artificially " aged " before use by immersion in dilute caustic soda solution, washing and steaming to remove any substances containing carbon or hydrogen.

The side tube of the U-tube is of the same external diameter as the capillary on the combustion tube. It is connected to the capillary so as to make glass-to-glass connexion by a piece of thick rubber tubing which has been impregnated

with vaseline to render it as gas-tight and non-hygroscopic as possible. (The tubing is impregnated by placing it under molten vaseline in a small flask connected to the pump and alternately evacuating and admitting air until bubbles no longer rise from the tubing on further evacuation. The pieces of tubing are then drained and wiped.)

The narrow end of the combustion tube is connected by means of a piece of impregnated tubing to the water absorption tube, which in its turn is connected to the carbon dioxide absorption tube, and this to a small safety tube containing phosphorus pentoxide on glass-wool. The other end of the safety tube is attached to a Mariotte bottle which serves to maintain the pressure at the junction between the first absorption tube and the combustion tube as nearly as possible equal to that of the outside air, thus obviating any leak at this point.

Fig. 58 (half actual size)

An absorption tube is shown in fig. 58. The entry tube of the water absorption tube is the same diameter as the narrow end of the combustion tube, and is attached to it with glass-to-glass connexion by means of impregnated rubber tubing. After passing two capillary constrictions in the entry tube, the gases pass into a chamber, and then through a small hole in the wall of this chamber into the filling material. The exit is of similar construction, except that the chamber is formed by a hollow, ground-glass stopper, which can be removed for refilling the tube. The carbon dioxide absorption tube is of the same construction but is about 20 mm. longer. It is connected to the water tube by impregnated rubber tubing with glass-to-glass connexion. An asbestos ring placed over the end of the combustion tube protects the water tube from the heat from the mortar, while condensation in the capillaries of this tube is prevented by keeping them warm with a metal hook attached to a metal rod fitting into a pocket in the heating mortar, as shown in fig. 56. The water absorption tube is filled with glass-wool which has been cut up and shaken with phosphorus pentoxide, plugs of glass-wool being placed at the ends of the filling next to the openings into the chambers. The carbon dioxide tube contains a small plug of glass-wool,

the absorbent (ascarite), and lastly a short plug of glass-wool next the stopper.* The stoppers of both tubes are fixed in place with a little Krönig cement. When not in use the absorption tubes are closed by means of glass rods and impregnated rubber tube connexions, and kept near the balance.

Conduct of the determinations.—Carbon-hydrogen combustions are run in series, each determination requiring about 50 min. The apparatus is first inspected to see that the Mariotte flask is full and that the gas-holders contain gas. The mouth of the combustion tube is then cleaned with a piece of cotton wool on the end of a wire, the stopper is replaced, and the oxygen turned on. The long burner is then turned on gently, and the burner under the heating mortar is lighted. The tube is now given a preliminary heating for about half an hour, during which the bubble rate is adjusted so that about 4 ml. of gas pass through the tube per minute. Meanwhile the rubber connecting tubes are cleaned with cotton wool slightly moistened with glycerine, being afterwards wiped with dry cotton wool. During ten minutes of the half-hour the part of the tube which will contain the boat is also heated as for a combustion. After the preliminary heating, a sample of the substance to be analysed is weighed into the platinum boat, the ends of the absorption tubes are cleaned inside, the outsides of the tubes are wiped with moist and dry chamois leathers, the water tube being treated first, and the tubes are then placed, without being further touched with the hands, on a stand near the balance for ten minutes. The water tube is then placed on the hooks over the left-hand pan of the balance, being handled with a holder only. After five minutes standing with the doors of the balance open, the tube is weighed to 0·01 mg. only. The ascarite tube is then weighed in the same way and, immediately after, the tubes are connected together, stopper to stopper. The water tube is next joined to the combustion tube, and the safety tube leading to the Mariotte flask is connected to the ascarite tube. Care must be taken when making these connexions that the rubber tubes always point in the same direction and that there is glass-to-glass contact at all the joints. The stream of water from the Mariotte flask is next started, the

* The arrangement of the U-tubes and the fillings of the absorption tubes given here are those recommended by Dr. J. W. Matthews, Imperial College of Science and Technology.

hook is placed over the capillary of the water absorption tube, and a piece of moist flannel over each absorption tube. The boat is then introduced into the combustion tube to a position about 30 mm. from the filling. A bubble count is now taken, and if necessary the pressure is adjusted by means of the Mariotte bottle.

When the gas rate is 4 ml. per minute the heating of the sample is begun, the tube being heated with the movable burner at some distance from the boat on the far side from the filling. The burner and gauze are gradually approached nearer to the boat, the contents of which are distilled out on to the tube and along it, until they are driven into the filling. The heating should be carried out so that the gas rate is maintained as nearly as possible constant at 4 ml. per minute. (To ensure this it is best to move the gauze toward the boat a few millimetres at a time, following each movement of the gauze with a corresponding movement of the Bunsen burner.) The combustion up to this point should take about ten minutes, 40 ml. of water having collected from the Mariotte flask. Air is now turned on in place of oxygen, and the heating with the movable burner repeated as before, the time taken being also ten minutes. The air is allowed to pass for a further fifteen minutes, during which a fresh sample may be weighed into a second platinum boat. At the end of this time the hands are washed to render them as cool as possible. The stream of water from the Mariotte flask is stopped, the absorption tubes are disconnected, first from the safety tube, then from the combustion tube; they are separated, and the end tubes wiped inside with a little cotton wool. The tubes are then prepared for weighing exactly as before, and left, side by side, on their stand near the balance for ten minutes. During this interval the air is turned off, the boat is removed from the combustion tube, the end of the tube cleaned if necessary, and the oxygen again turned on. The connecting tubes are wiped inside and out with a small wad of cotton wool just moistened with glycerine, the excess of glycerine being removed with a wad of dry cotton wool. When the water tube has been ten minutes outside the balance case it is placed on the balance for five minutes, with the doors of the balance case open. It is then weighed, and the ascarite tube is weighed immediately after. The tubes are at once connected to one another and to the apparatus, exactly as before, the boat with the new sample is introduced,

and the next combustion commenced. The final weights of the absorption tubes after any combustion are taken as the initial weights for the next. Before undertaking a series of analyses a sample of a pure substance of known composition, such as benzoic acid, should be analysed.

For *liquids* short capillary tubes, about 1 mm. in diameter, are used. Tubing of this size is heated until the walls fall together at one point; the collapsed portion is then drawn out and cut, leaving a short length of rod attached to the capillary to serve as a handle. A *small* pellet of potassium chlorate is then melted into the closed end of the tube, and the open end drawn out to a hair capillary about 15 mm. long. The tube is then weighed and the liquid introduced by warming the wide portion of the tube and placing the end of the capillary beneath the surface of a drop of the liquid on a microscope slide. When sufficient liquid has been drawn up, the outside of the tube is wiped and the liquid centrifuged down to the potassium chlorate. The tube is then sealed carefully and again weighed. It is placed on the platinum boat with the glass rod through the hole in the handle of the boat; the capillary tip is broken off and placed in the boat. The combustion is then carried out as already described.

C. Determination of Nitrogen

1. **Micro-Dumas Method.***—As in the large-scale method, the substance is decomposed by heating with copper oxide and the volume of nitrogen obtained is measured.

A combustion tube with a narrow end is filled as shown in fig. 59. A small wad of asbestos (*a*) is placed at the narrow end, then 130 mm. of freshly ignited "wire-form" copper oxide (*b*) followed by a second asbestos plug (*c*). A portion of the copper oxide 40 mm. long (*d*), farthest from the narrow end of the combustion tube, is reduced by heating in a current of hydrogen. The remainder of the filling is introduced afresh for each combustion and is described below. The carbon dioxide required to expel the nitrogen from the combustion tube is generated in a Kipp apparatus, with special precautions for obtaining a gas free from air. The water used to dilute the acid is boiled with the marble before use, and a second source

* *Pregl*, loc. cit., p. 81.

of carbon dioxide is arranged to deliver gas into the top bulb of the main generator to keep the acid there free from air. The exit tube of the Kipp is bent upwards inside the bulb to prevent spray from being carried over, and is connected to

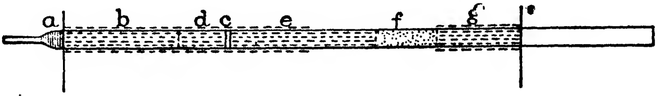


Fig. 59

the combustion tube by means of a bent capillary tube, tapered at the end where it fits into the stopper of the combustion tube. The narrow end of the combustion tube is connected to the micro-nitrometer by means of a cock with a bore of special construction for the delivery of very small quantities of gas, and fitted with a long handle for ease of adjustment. When

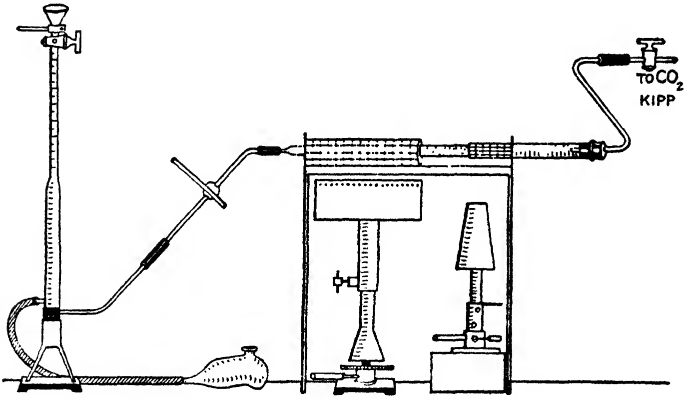


Fig. 60

the apparatus is not in use this cock is left closed and the tap from the Kipp left open so that the combustion tube is filled with carbon dioxide under pressure from the Kipp. The micro-nitrometer, shown in fig. 60, has a capacity of 1·5 ml., and is graduated in steps of 0·01 ml., the volume being estimated to 0·001 ml., using a reading lens. The nitrometer contains mercury to a level midway between the side tube leading to the combustion tube and the inlet tube from the levelling bulb.

It is filled with 50 per cent caustic potash solution containing a little barium hydroxide to prevent foaming.

Conduct of the combustion.—Before commencing a determination, the nitrometer is charged with potash solution, the taps are lubricated with the smallest possible quantity of vaseline, and, especially if the apparatus has been idle for some time, the Kipp apparatus is allowed to deliver gas freely for a short time so as to drive out any air. About 3–5 mg. of the material to be analysed are weighed out and transferred to a small test tube closed with a well-fitting cork. The taps leading to the nitrometer and Kipp apparatus are turned off and the combustion tube disconnected. The temporary filling is removed and the tube refilled as follows:

About 100 mm. of freshly ignited wire-form copper oxide (*e*, fig. 59) are introduced above the permanent filling, followed by a few millimetres of powdered and freshly ignited copper oxide, best prepared by grinding up the wire-form. This latter prevents the sample from falling into the coarse oxide which is heated before the combustion commences. A small quantity of fine copper oxide is now added to the tube containing the sample, the tube is corked and well shaken, and the mixture transferred to the combustion tube through a funnel. The test tube is rinsed out twice with small amounts of the powdered copper oxide and the rinsings added to the contents of the combustion tube. The total length of the temporary filling (*e* and *f*) should now be about 140 mm. A further 40 mm. of coarse copper oxide (*g*) are added, and two protecting rolls of wire gauze are slipped over the tube, which is placed in its stand (fig. 60). It is then joined, first to the empty nitrometer, care being taken that there is glass-to-glass connexion, then to the carbon dioxide generator, after clearing the end of the combustion tube with a piece of cotton wool, so as to free it from particles of copper oxide. A gentle stream of carbon dioxide is passed through the apparatus with the tap leading to the nitrometer open. After a few minutes the tap leading to the nitrometer is nearly closed and the nitrometer is filled with potash solution. If micro-bubbles of diameter less than 0·2 of a scale division are obtained the combustion is started, since no appreciable amount of gas collects with bubbles so small. The tap leading to the Kipp apparatus is closed, that leading to the nitrometer being fully opened. The permanent filling is then heated to a dull red

heat with a tube burner, and a Bunsen burner is used to heat the temporary filling, starting at the end nearest the Kipp, a roll of gauze being used to protect the part of the tube being heated. The burner is gradually brought nearer to the permanent filling as the combustion proceeds, at such a rate that one or two bubbles rise in the nitrometer every three seconds. When the bubbles cease the combustion is complete. The long-handled cock is now closed, the tap leading to the Kipp is fully opened, and the long-handled cock adjusted so that gas bubbles rise in the nitrometer at the same rate as before. The heating of the sample with the Bunsen burner is repeated, after which the burners are turned out. When micro-bubbles once more appear, the levelling tube of the nitrometer is hung at the top of the instrument, the long-handled cock is closed, and the nitrometer is detached from the combustion tube, leaving the cock attached to the combustion tube. The determination up to this point requires about 30 min. After ten or fifteen minutes, the gas in the nitrometer is brought to atmospheric pressure by adjusting the level of the reservoir, the volume and temperature of the gas are taken, and the barometer is read. A correction of 2 per cent of the volume is subtracted from the volume of the gas to allow for the volume of potash solution clinging to the walls of the nitrometer and for the vapour pressure of the solution. Substances difficult to burn may be mixed with a small quantity of potassium chlorate in addition to the copper oxide. Liquids may be placed in tubes similar to those used in carbon-hydrogen combustions, the tube being protected with a small roll of oxidized copper gauze. The filling of the combustion tube is proceeded with as before.

2. **Micro-Kjeldahl Method.***—The method follows that on the large scale. The nitrogen is first converted into an ammonium salt which is decomposed with alkali and the ammonia formed steam-distilled into a known volume of standard acid, the excess of acid being titrated against a standard alkali. Approximately ·01 N. solutions of acid (HCl or H_2SO_4) and alkali (NaOH) are used.

The decomposition of the substance is carried out in hard-glass tubes about 16 cm. long, shaped like small Kjeldahl flasks. The samples of 3–5 mg. are weighed out into the flasks,

* *Parnas and Wagner*, Biochem. Zeit., 125, 253 (1921), modified by *Pregl* loc. cit., p. 109.

1 ml. of concentrated sulphuric acid is added to each, followed by a few milligrams of a mixture of one part of potassium sulphate to three parts of copper sulphate to act as catalyst. The tubes are then heated over small burners for about ten minutes, with the open ends of the tubes resting in a draught hood. At the end of this time a drop or two of 30 per cent hydrogen peroxide solution (e.g. Merck's pure perhydrol *) are added to the contents of the flasks, the addition being repeated every few minutes until the reaction mixture becomes colourless. A control experiment in which everything except the sample is added as above is set going at the same time.

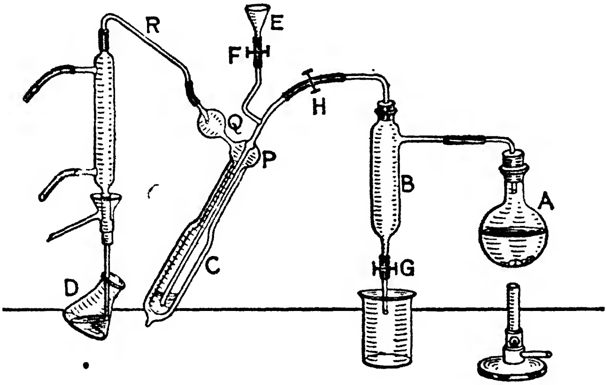


Fig. 61

During the decomposition the distillation apparatus is prepared. The arrangement is shown in fig. 61. Water, to which a few drops of sulphuric acid have been added, is boiled in the hard-glass flask A and the steam passes through the trap B into the hard-glass vacuum-jacketed distillation vessel C. The steam and ammonia from C pass through the traps P and Q into the silver condenser tube R, and so into the standard acid in the hard-glass flask D. A glass condenser tube cannot be used because of the solution of alkali from the glass. The solution containing the ammonium salt, and the alkali, are introduced by means of the funnel at E.

Before carrying out a distillation, steam is passed into the vacuum-jacketed vessel until a few millilitres of water have

* *Not* Merck's "Tropical" Perhydrol, which is stated to contain nitrogen.

collected in it, the clips at F and G being closed. The flame is then removed from under A, whereupon the liquid sucks back from C into B. This is repeated several times, the funnel E being also rinsed each time.

The determination is carried out as follows:

The clip at H is closed, the steam being allowed to pass out through G. The receiving flask D, containing the equivalent of 1 ml. of 0·01 N. acid for each 0·1 mg. of nitrogen, with a drop of methyl red as indicator, is placed in position with the end of the condenser tube just below the surface of the liquid in the flask. The contents of the tube in which the decomposition has been carried out, after cooling and diluting with 1 ml. of distilled water, are now poured carefully into the distillation vessel through the funnel, and the tube and funnel are washed out with three 1 ml. portions of water. 7 ml. of 30 per cent sodium hydroxide solution containing 5 per cent of sodium thiosulphate (to prevent frothing and to decompose copper complexes) are now added to the contents of the distillation vessel, the clip leading to the funnel is closed, and steam is passed into the distilling flask by opening the clip H and closing G. The distillation is continued for four minutes, when the receiver is lowered until the exit tube is no longer in the liquid, and the distillation carried on for a minute longer. The end of the condenser tube is then washed carefully with distilled water neutral to methyl red, the wash liquid being caught in the receiver which is then removed. On taking away the burner from under A the residue in the distillation vessel is automatically removed, and the apparatus may then be washed out as before. A blank test should always be run before a determination is undertaken. The excess of acid in the receiver is titrated against 0·01 N. alkali until the indicator turns yellow, then a few drops of the standard acid are added, the solution boiled to eliminate carbon dioxide, and again neutralized with the alkali. The exact volume of standard acid equivalent to the nitrogen present in the sample is then ascertained and the nitrogen content of the substance calculated.

The alkali and acid, the latter standardized with pure sodium carbonate, are contained in burettes of 10 ml. capacity graduated in 0·02 ml. steps. All washings during the titrations must be carried out with water, which is neutral to methyl red.

D. Determination of Halogens and Sulphur *

In the estimation of halogens or sulphur the substance is burned in a stream of oxygen, and the gaseous products are absorbed, in the case of halogens in an aqueous solution of sodium carbonate and sodium bisulphite, in the case of sulphur in a dilute aqueous solution of hydrogen peroxide. The halogen is then precipitated as silver halide, or the sulphur as barium sulphate, in the usual way.

The combustion and absorption are carried out in a tube of hard glass, 60 cm. long, narrowing at one end to a bore of about 0·5 mm. diameter (fig. 62). Near the narrow end is situated a spiral of glass 200 mm. long, on which the absorbing

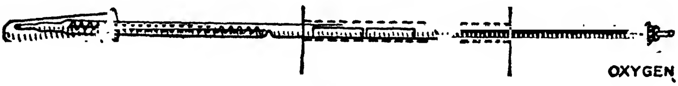


Fig. 62

liquid is carried. The tube also contains two Z-shaped platinum contact pieces, which act as catalyst, placed about 4 cm. from the spiral. The tube is surrounded by a piece of wire gauze in the region of the platinum contacts, which are heated with a long burner. The boat containing the substance to be analysed is placed about 5 cm. from the contacts and is heated with a Bunsen burner, the tube being protected by a roll of wire gauze. Oxygen for the combustion is obtained from a cylinder, and after passing through a suspension of sodium bicarbonate in water, is led into the combustion tube through a tapered capillary fitting into a stopper in the end of the combustion tube.

Halogen Determination.—The tube and spiral are first washed with chromic acid mixture, distilled water and alcohol, and dried by aspirating clean, warm air through the tube. The spiral is then moistened with a concentrated solution of sodium carbonate to which a few drops of sodium bisulphite have been added. The platinum contacts, which have been cleaned by boiling in dilute nitric acid and glowing in a Bunsen flame, are now placed in position in the tube, which rests on its stand with a hard-glass tube, moistened with the sodium carbonate-bisulphite mixture, over the narrow end. Finally the

* *Pregl*, loc. cit., p. 118.

boat, with 3–5 mg. of material weighed into it, is introduced, and oxygen passed through the tube at a rate of about 2 bubbles a second. The burner under the platinum contacts is lighted, and when these are red hot the combustion is started by heating the tube about 10 mm. from the boat and on the far side from the contacts. The material is driven out of the boat and moved along to the platinum contacts by moving the burner and gauze. When the contacts are reached the burners are extinguished and the apparatus allowed to cool in a current of oxygen. The combustion should take about 35 minutes. When cold, the boat and platinum contacts are removed from the tube, which is taken from the stand while keeping the test tube over the narrow end. The gauzes are removed after closing the wide end of the tube with a plug of cotton wool. After removing the plug, the tube is washed out with water, two or three drops of bisulphite solution having first been introduced into the tube through the wide end. The washing is repeated twice, the outer surface of the tube being also rinsed into the test tube. The sulphite in the washings is now oxidized by adding two drops of pure 30 per cent hydrogen peroxide solution and warming on a water bath for a few minutes. After cooling, 3 ml. of 5 per cent silver nitrate solution containing one-third its volume of concentrated nitric acid are added and the heating continued for 15 minutes. The filtration may then be carried out, after thorough cooling, in the apparatus shown in fig. 63. The filter tube F contains an asbestos mat filter supported on a coarse sintered glass plate. The asbestos is washed free from soluble matter by means of chromic acid mixture, water, warm dilute nitric acid, water, and finally alcohol. The tube is dried by placing it in

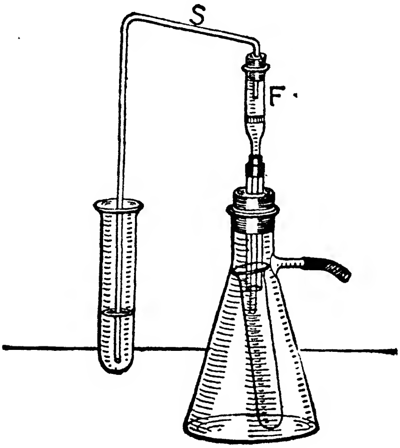


Fig. 63

a hole in a metal block which is heated from below, and aspirating a stream of dry, dust-free air through the tube, which is dried in 5 minutes, wiped in moist and dry chamois leathers, and placed near the balance for 15 minutes to come to thermal equilibrium. It is then weighed after 5 minutes on the balance with the doors open, being weighed to 0·005 mg. only. When further washing and drying does not cause any change in the weight of the tube it may be used for a determination. The filter tube is attached to a suction apparatus as shown in fig. 63, and the filtration performed by drawing liquid and precipitate through the siphon tube S. The test tube is rinsed alternately with 1 per cent nitric acid and alcohol until all the precipitate has been transferred to the filter tube, when the end of the siphon tube is washed on to the filter, and the filter tube filled up to the brim with alcohol. When this has passed through, the filter tube is removed, dried, and weighed as before.

Special precautions are necessary when iodine is determined by this method. Elementary iodine may be formed during the combustion. If this should sublime in the cool part of the combustion tube, it may be driven into the portion containing the spiral by cautious heating. A larger quantity of hydrogen peroxide (4–5 drops) is used in the after treatment of the washings from the combustion tube. To avoid formation of iodate, the washings are not warmed but merely allowed to stand for ten minutes before precipitation.

Sulphur Determination.—The apparatus is the same as for the halogen estimation. The spiral is moistened with 6 per cent perhydrol, which serves to oxidize any lower oxides of sulphur. The process of combustion is similar to that for the halogens except that the rate of passage of oxygen is less, being about half the speed for halogens. This slower rate is necessary on account of the difficulty with which sulphur trioxide is absorbed by the aqueous perhydrol. At the close of the combustion, the tube is washed out with 1 per cent hydrochloric acid into a hard-glass dish. Two small crystals of barium chloride are added to the washings, and the dish is covered and heated on the water bath for a few minutes. The contents of the dish are then evaporated to dryness, a small quantity of dilute hydrochloric acid is added, and the precipitate transferred to a micro-Neubauer crucible with a filter mat of platinum-iridium sponge. This is facilitated by

pouring the liquid down a thin glass rod. The precipitate is washed several times alternately with 1 per cent hydrochloric acid and alcohol, and finally with the dilute acid. The crucible, with its lid on, is then heated to a dull red heat inside a larger platinum crucible. When cold, the washing with dilute acid is repeated, after which the crucible is again heated, and finally cooled and weighed. By this means the barium sulphate is washed free from barium chloride.

This is the method given by Pregl. The precipitation may also be carried out in small weighed micro-beakers,* the filtration being performed by suction through filter sticks (short porcelain tubes with a filter mat of unglazed porcelain at one end), which are weighed with the beakers. The evaporation to dryness is dispensed with and the precipitate is dried without being ignited.

E. Determination of Metals †

As in the case of the large-scale methods, the estimation of platinum, gold, and silver may be very simply carried out by gentle heating of the material. Such a determination is usually accomplished incidentally during the carbon and hydrogen estimation, all that is necessary being a determination of the weight of the boat and residue of metal at the conclusion of the combustion. Copper may be estimated as oxide after a carbon-hydrogen estimation, provided care is taken that no reduced copper is formed in the boat during the combustion.

The salts of sodium, potassium, calcium, barium, magnesium and cobalt may be quantitatively converted (in the absence of phosphates) to sulphates by heating with sulphuric acid in a platinum boat in the apparatus shown in fig. 64. The boat is placed inside a platinum cylinder, 4 cm. long and 8 mm. diameter, which prevents loss from the boat by spirting or creeping. Boat and cylinder are weighed together. The salt is weighed into the boat and covered with one or two drops of 20 per cent sulphuric acid, the quantity of acid being kept as small as possible. The boat is then slipped into the platinum cylinder which is placed in one end of a hard-glass or silica tube, clamped horizontally, and through which a stream of air or oxygen may be passed from the other end. The tube is wrapped

* Procedure recommended by Dr. J. W. Matthews.
† *H. I. Coombs*, Biochem. J. 1927, **21**, 404.

in wire gauze in the neighbourhood of the boat and is heated carefully some distance from the boat until fumes of sulphuric acid appear. These soon cease, whereupon the boat is heated strongly for two or three minutes with the flame directly under the boat and without the gauze. This ensures complete con-

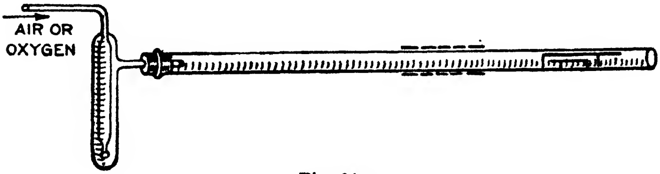


Fig. 64

version of acid sulphate to the normal salt, thus dispensing with the need for heating with ammonium carbonate. It is best to carry out the final heating in oxygen, and to use this gas throughout for substances of high carbon content. When the direct heating is finished the cylinder and boat are removed from the tube, placed on a copper block under a dust cover, and are ready to be weighed in a few minutes.

VII. DETERMINATION OF EQUIVALENTS OF ACIDS AND BASES

A. Acids

The equivalent of an acid can be determined (1) by direct titration with standard alkali, (2) by the preparation of a metallic salt, e.g. the silver salt, and its analysis, i.e. the determination of the percentage of metallic radical in the salt.

1. **By Titration.**—The most suitable alkali for titrating is barium hydroxide solution, as this can be kept free from carbonate. A roughly 0·05 N. solution is prepared and accurately standardized by means of pure oxalic or succinic acid (Analar), using phenolphthalein as indicator. At least two independent standardizations should be made and, if the supply is set up in the laboratory, the standardization should be checked at frequent intervals.

An apparatus for a permanent baryta supply is depicted

in fig. 65. The tower and tube are filled with soda-lime which is kept in position by loose plugs of cotton wool, thus perventing fine particles being blown into the solution. The large bottle has a capacity of over four litres.

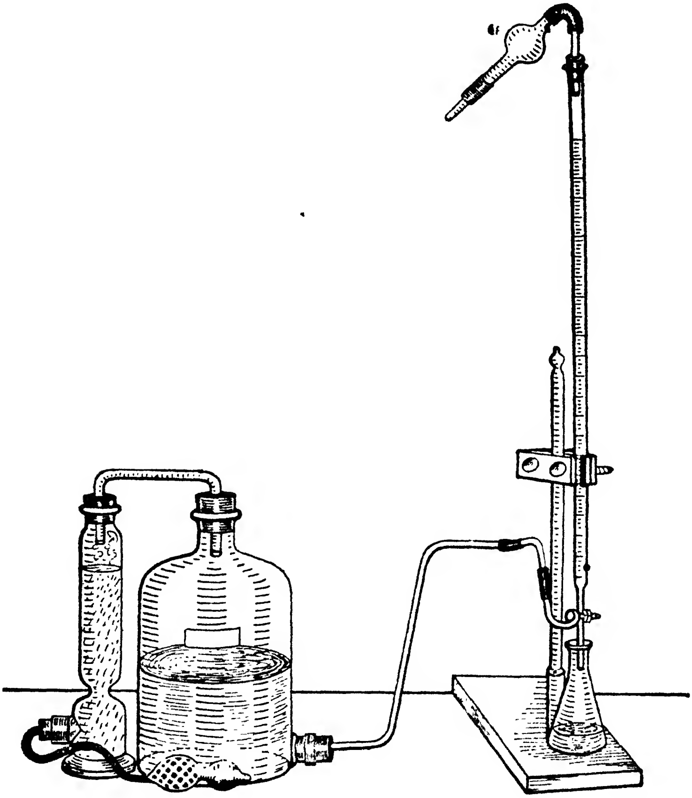


Fig. 65

A hot concentrated solution of the hydroxide is prepared and allowed to cool; the saturated solution at 15° is approximately 0·4 N. To obtain an approximate 0·05 N. solution 3·5 litres of freshly boiled distilled water are placed in the bottle and 500 ml. of the saturated baryta solution added. The bottle is shaken thoroughly, the connexions made to the tower

and to a 3-way standardized burette. The latter is filled several times by means of the blow-ball and the liquid rejected.

To determine the equivalent of an unknown acid a definite amount is weighed out accurately, the weight actually taken being sufficient to require between 20 and 50 ml. of the standard alkali. To ascertain this amount a rough titration is made with about 0·1 g. of the acid.

If the acid dissolves in water, a solution in freshly distilled water should be employed. If insoluble in water, a mixture of alcohol and water or alcohol alone may be used, but in all cases the alcohol should be previously tested in order to make sure that it is free from acid. (Ordinary alcohol is liable to contain small amounts of acetic acid.) The indicator used throughout is phenolphthalein, as the end point is extremely sharp when a strong alkali like barium hydroxide is used. If sodium hydroxide is used as the standard alkali, it should be carefully protected from atmospheric carbon dioxide, as small amounts of carbonate render the end point less delicate, and further, the continual absorption of carbon dioxide materially affects the concentration of the alkali when phenolphthalein is used as indicator.

If any but freshly distilled water is used for dissolving the acid, a blank experiment should be made and the amount of alkali required for the water determined.

The average of several readings is taken,* and from the data obtained the amount of acid required to neutralize the gram equivalent of barium hydroxide is calculated.

2. By the Analysis of a Salt.

Silver Salts.—If the percentage of metallic radical in a salt is determined, the equivalent of the acid can be calculated. For organic acids the salts generally used are those of silver, but salts of barium, calcium and copper are in some cases suitable for this purpose.

The great advantage of silver salts is that (*a*) they are almost invariably sparingly soluble in water, hence readily prepared; (*b*) they crystallize from hot water without water of hydration; (*c*) they decompose readily on heating, leaving a residue of metallic silver. The salt is prepared as indicated in Chap. XIII, A, dried and kept in a desiccator over sulphuric acid.

A small amount (0·2–0·5 g.) is placed in a weighed porcelain

* The readings should be approximately the same, and for 20 ml. should not vary more than 0·1 ml.

crucible, gently heated with the lid on, and the temperature gradually raised until the crucible is red hot and a pure white residue of silver remains. Great care has to be taken at the beginning of the heating, otherwise vigorous decomposition occurs and loss by spirting. In most cases, combustible gases are formed and take fire as they are evolved. After the first weighing the crucible is heated again and reweighed in order to make sure that the weight is constant.

From the results of the analysis the weight of salt which contains the gram atom of silver, i.e. 107·93 g. of silver, is calculated. This represents the equivalent weight of the silver salt, and the equivalent of the acid is obtained by subtracting from this number the atomic weight of silver and adding the atomic weight of hydrogen—

$$\text{Equivalent of acid} = \text{Equivalent of Ag. salt} - 107{\cdot}93 + 1{\cdot}008.$$

Barium Salts.—In many cases the barium salts of the acids are insoluble in water, e.g. barium oxalate, or are sparingly soluble and crystallize well (Exp. 78). As barium salts are apt to contain water of crystallization it is advisable to heat the salt in an air oven at a fixed temperature (110–140° is usually sufficient) until the weight is constant.

The salt is analysed and the percentage content of barium determined (see p. 69). The weight of barium salt which contains one equivalent of barium (68·7) is calculated. This is the equivalent of the salt, and from this the equivalent weight of the acid is readily obtained.

Calcium Salts.—As in the case of barium salts, calcium salts are often readily prepared. These may be analysed by simple ignition to constant weight in a platinum crucible (see p. 69). The weight of salt which yields one equivalent weight of calcium oxide (28·03) is the equivalent weight of the salt. From this the equivalent of the acid may be obtained as above.

Copper Salts are especially useful in the case of amino-acids, as they can be analysed by heating to constant weight, the residue being cupric oxide.

B. Bases

1. **By Analysis of a Platinichloride (Chloroplatinate).**—Most organic bases resemble ammonia in the formation of platinichlorides which are sparingly soluble and which crystallize well.

The platinichloride is prepared by dissolving the base in a slight excess of moderately concentrated hydrochloric acid * and adding a fairly concentrated solution of platinic chloride. In most cases if the ordinary laboratory solution of platinic chloride is used (about 2·5 per cent) no precipitate is formed, as the platinichlorides are sparingly soluble in water. With a 10 per cent solution crystalline precipitates are readily formed.

The precipitate is filtered, washed with a very small amount of water, dried, and analysed in the same manner as the silver salt of an acid. The final residue consists of metallic platinum. The platinichlorides of the organic bases resemble ammonium platinichloride in that they contain 2 g. equivalents of base in the gram molecule, e.g.

$$(NH_3)_2H_2PtCl_6 \text{ and } B_2H_2PtCl_6,$$

where B represents the equivalent weight of the base.

The method of calculation is to find the gram molecular weight of the platinichloride, i.e. the number of grams of salt which yield the gram atom (194·8) of platinum.

Then the equivalent of the base

$$= \frac{\text{molecular weight of platinichloride} - (2{\cdot}016 + 194{\cdot}8 + 6 \times 35{\cdot}45).}{2}$$

2. **By Titration.**—The equivalent of a base may often be determined by preparing a crystalline salt with some mineral acid or even organic acid—e.g. the hydrochloride, sulphate, acetate, benzoate—purifying the salt, and then titrating the amount of acid present in the salt by means of standard alkali (barium hydroxide solution, p. 87), using phenolphthalein as indicator. The weight of base which is combined with the equivalent weight of the acid will be the equivalent weight of the base.

Salts prepared in aqueous solution may contain water of crystallization, and in such cases the preparation in ether or other non-aqueous solution is often satisfactory.

Experiment 8.—Prepare aniline sulphate from dilute sulphuric acid and aniline and recrystallize from water. Determine the equivalent of the base by titrating the amount of sulphuric acid present in a known weight of the dry salt.

* In a few cases, e.g. α- or β-naphthylamine, the hydrochloride is very sparingly soluble in cold water or hydrochloric acid.

Experiment 9.—Prepare α-naphthylamine hydrochloride by passing dry hydrogen chloride into a solution of α-naphthylamine in dry ether. Filter off the precipitated hydrochloride by means of a pump, wash with ether and dry in a desiccator. Make a standard solution of the salt in water and titrate with standard baryta.

The methods described above are *not* methods for determining molecular weights. In the case of an acid, for example, it is necessary to know the *basicity*. Similarly with bases, the methods only yield molecular weights when the *acidity* of the base is known. If the base is known to be mono-acidic, its hydrochloride will be represented by the formula XHCl, and its platinichloride as $X_2H_2PtCl_6$, where X represents a molecule of the base. The gram molecule of base will therefore be half the amount equivalent to one gram atom of platinum, or, in other words, the equivalent and molecular weights will be identical. If, however, the base is diacid, e.g. $C_6H_4(NH_2)_2$, the platinichloride will be of the form XH_2PtCl_6, and the molecular weight will be double the equivalent.

VIII. DETERMINATION OF MOLECULAR WEIGHTS BY PHYSICAL METHODS

A. Vapour-density Methods

The common vapour-density method used in chemical laboratories is the Victor Meyer method (fig. 66).

The inner vessel (fig. 67) is thoroughly cleaned and dried, and a plug of dry asbestos wool is placed in the bottom. In the bulb of the outer jacket or mantle is placed a liquid the boiling-point of which is considerably higher than the boiling-point of the substance under investigation, e.g. water may be used when the vapour density of a volatile liquid like ether (b.p. 36°) is to be determined. If a higher boiling liquid is required, aniline (b.p. 185°) may be used, or for still higher temperatures ethyl benzoate (213°), amyl benzoate (262°), diphenylamine (310°), anthracene (335°), anthraquinone (368°), sulphur (448°).

A glass mantle may be used, but for temperatures above 310° a copper vessel or, in the case of sulphur, an iron vessel must be used. The inner tube is held in position by a clamp, and the liquid in the jacket is boiled so that the greater part of the jacket is filled with the vapour of the boiling substance. The delivery tube attached to the inner vessel is placed under water in a pneumatic trough and the stopper placed in the open end of the vessel. By this means it is easy to tell when the air

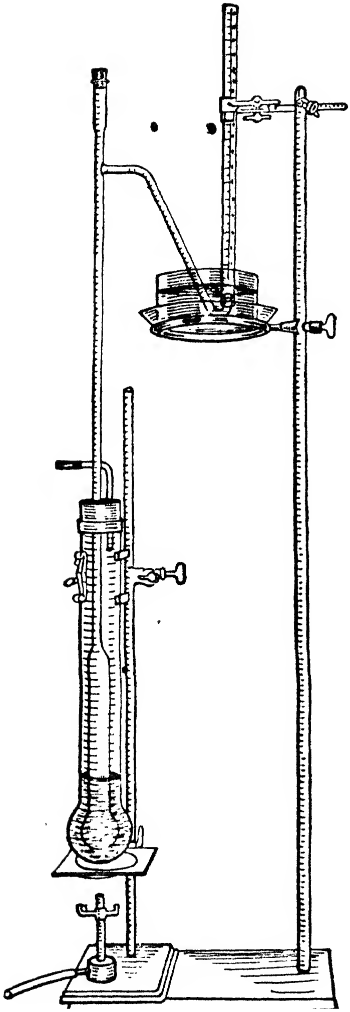


Fig. 66

Fig. 67

in the inner vessel is at a constant temperature, namely, by observing when no more air bubbles escape from the

delivery tube.* When a constant temperature has been attained the end of the delivery tube is placed under a graduated measuring tube filled with water.† The stopper is then removed, a known weight of the substance under examination is introduced, and the stopper immediately replaced. If the substance is a solid, a small roll or pastille can often be made by means of a small pastille press (fig. 68) ‡ and then dropped in. If a liquid is being used, it is better to introduce it in a small bulb tube (fig. 69), or a minute stoppered bottle (fig. 70). In either case the vessel used must slide down the neck readily and the amount of material used must never be too large. The vapour to which it gives rise should not more than half fill the bulb of the inner vessel.

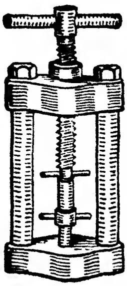


Fig. 68

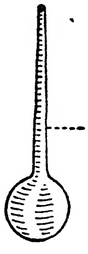


Fig. 69

Fig. 70

If a bulb tube is used, it is most readily filled by warming the bulb and then allowing it to cool while the open end is immersed in the liquid. When a small amount of liquid has entered, the bulb is heated until the liquid boils, and then cooled as before, and as the vapour condenses fresh liquid is drawn up until the whole tube is nearly filled. If the liquid is very volatile, the bulb should be sealed during weighing and the sealed end broken off just before introducing into the vapour-density apparatus.

If it is desired to carry out three or four determinations, it is not necessary to dismantle the apparatus. The measuring tube is removed and the trough lowered; a current of air is passed through the inner tube whilst it is still at the constant temperature and by this means the vapour of the liquid is driven out.

* A certain amount of care is required in conducting the experiment, as if the flame under the mantle is blown about by currents of air, the temperature may fall and water may be sucked back into the inner vessel.

† The trough and measuring tube may be replaced by an ordinary Hempel gas burette, in which the displaced air is measured.

‡ Another method of obtaining a solid rod of material suitable for dropping into the inner vessel is to take a glass tube some 2 mm. wide and 6 cm. long. The molten solid is drawn up into this tube and allowed to solidify; to remove the solid the tube is heated very gently above a flame until the surface just melts, when it can be pushed out by means of a copper wire.

N.B.—A second determination should never be made before the vapour produced in the first determination has been removed, as otherwise the gas driven over in the second determination consists of a mixture of air and vapour, and when this mixture bubbles through the cold water the vapour is condensed, and thus the volume of gas measured is considerably less than the volume of gas displaced by the vapour produced in the second determination.

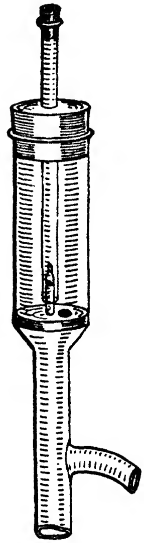


Fig. 71

The volume of air measured under given conditions of temperature and pressure (viz. the atmospheric pressure and the temperature of the water) is reduced to normal temperature and pressure, care being taken to allow for the pressure of aqueous vapour. The value of this pressure for different temperatures is given in Table XXI, Appendix. The weight of this volume of hydrogen is then readily calculated, since 1 ml. of hydrogen at N.T.P. weighs 0·00009 g., and the ratio—

$$\frac{\text{wt. of substance taken}}{\text{wt. of hydrogen}}$$

gives the vapour density.

Various modifications of the original apparatus have been suggested.

1. In order to avoid removing and replacing the cork, the upper part of the inner tube can be arranged as follows. The small tube or bottle rests on a piece of glass rod, which passes through a second side tube, and when the temperature is constant and it is desired to lower the bottle the glass rod is withdrawn by pulling it through the rubber tube by means of which it is attached to the side tube. This apparatus should not be used if the substance is very volatile.

2. Another method of releasing the small bulb is suggested by Patterson * (fig. 71). In the upper and wider part of the inner tube a circular piece of cork (¼ in. thick) is introduced. Eccentrically in this cork a circular hole is bored which will admit of the passage of the bulb. The bulb itself is retained in position by means of a glass tube passing in a slightly oblique position through the rubber bung at the top of the

* C. N. 1908, **97**, 73.

apparatus. This tube is also corked, and when it is desired to release the bulb the tube is moved (the elasticity of the rubber bung permits this without any leak) until the bulb is over the opening of the cork, when it falls to the bottom of the V. Meyer tube.

B. Freezing-point Method—Cryoscopic Method

The introduction of a solute into a solvent lowers its freezing-point and within certain limits the lowering is directly proportional to the concentration of the solute. Raoult has shown that gram-molecular equivalents of different substances dissolved in equal weights of the same solvent lower the freezing-point of the solvent to the same extent.

The molecular lowering of the freezing-point of a solvent is the lowering which would be produced when a gram molecular weight (M) of a solute is dissolved in 1000 g. of solvent and is usually denoted by C. This varies for different solvents and is determined experimentally by using substances of known molecular weight, e.g. if p g. of a substance of molecular weight M, dissolved in 1000 g. of solvent, cause a depression of $\Delta°$ in the freezing-point of the solvent,

$$C = M^{\Delta}.$$

Values of C for some common solvents are as follows:

	Freezing-point (°C)	C
Water	0	1·86
Benzene	5·48	5·00
Acetic acid	16·75	3·90
Ethylene dibromide	7·92	11·8
Naphthalene	79·6	6·9
Phenol	39·6	7·2
Palmitic acid	59·9	4·4
Nitrobenzene	5·28	6·91
Camphor	176	49·8

1. **Rough Method.**—For substances of low molecular weight, approximate values may be obtained by the following procedure. A stout test tube—about 3 cm. in diameter—is fitted with

a stopper carrying a stirrer (platinum or nickel) and a thermometer graduated in tenths of a degree. The freezing-point of the pure solvent is first determined; 20–25 ml. of the solvent are introduced into the tube, which is then immersed in a bath which is kept at a temperature about 3–4° below the actual freezing-point, e.g. if water is the solvent a freezing mixture of ice and salt at about $-3°$ may be used. This is placed in a stout glass vessel, and may be protected by being surrounded with a woollen cloth. The liquid in the tube is kept stirred, and when the temperature registered by the thermometer in the liquid is some 0·3° below the correct freezing-point, the inner tube is removed and the stirring continued. The temperature falls a little farther until ice begins to separate, when it rises to the correct freezing-point, and will remain at that temperature for a few minutes, provided the ice and liquid are thoroughly mixed by gentle stirring. After the reading has been taken, the ice is melted and the operation repeated. The mean of several readings is taken as the correct freezing-point of the solvent. The operation is then repeated, using a solution of known concentration in place of the pure solvent. The freezing-point will be lower and again the mean of several readings is taken. From this depression M is calculated from the equation given above.

Experiment 10.—Using aqueous solutions of approximately 2·5, 5·0 and 7·5 per cent strength, determine the molecular weight of urea, acetic acid or phenol.

Fairly accurate results can only be obtained when the solvent and solute do not react with one another. If they combine to form a definite compound the results are not correct, owing to the fact that the concentrations of the substance are altered by the formation of the compound. Care should also be taken that the solvent employed does not cause the association or the dissociation of the solute. Thus the molecular weights of strong electrolytes should not be determined in aqueous solutions. Rough determinations of the molecular weights of many organic acids (cf. Exp. 10, where acetic acid is used) may be made in aqueous solution, provided the acids are not strongly ionized. The majority of carboxylic acids are not strong acids, and only slightly ionized. A further point to bear in mind is that the solvent must not cause the association of the solute. It is also essential that the crystals which separate on cooling and stirring should be crystals of

the pure solvent and not mixed crystals of solute and solvent; in other words, the solvent and solute must not form solid solutions.

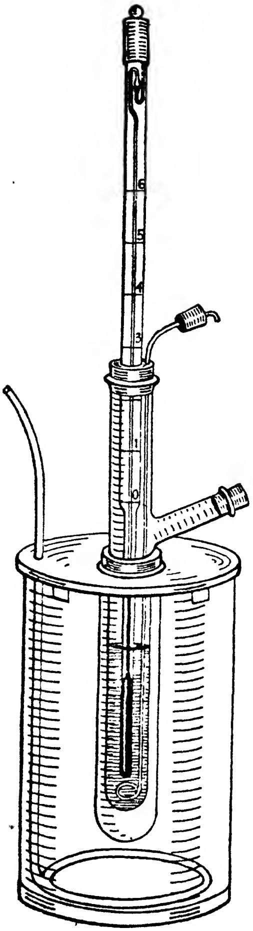


Fig. 72

2. **Beckmann Method.**—The cryoscopic method is usually carried out somewhat more carefully than described above in an apparatus (fig. 72) devised by Beckmann.

The freezing-point tube itself has a wide side tube through which the solute can be introduced, and is fitted into a wider tube by means of a rubber ring. This outer tube serves as an air bath, and keeps the freezing-point tube itself from coming into contact with the freezing mixture. The stirrer for the freezing-point tube is usually made of stout platinum wire, or of a platinum ring fused into a glass holder, which passes through a glass tube carried by the cork. The thermometer used, "the Beckmann thermometer" (fig. 73), is a delicate thermometer graduated in one-hundredths of a degree. As the whole scale of the thermometer has a range of some 6 degrees only, the instrument is so arranged that it can be used for solvents with very different freezing-points by an alteration in the amount of mercury contained in the bulb. For example, if it is desired to work with benzene solutions, as the freezing-point of benzene is 5·48°, it is necessary that the amount of mercury in the bulb is such that when the temperature is 5·48°, or some 1 to 2 degrees lower, the top of the mercury thread can be read off on the scale. If there is too much mercury in the bulb, the temperature of the thermometer is raised some 2 to 3 degrees above the actual temperature required, the excess of mercury passes over into the reservoir, and if the instrument is

gently tapped this excess separates from the main thread and falls into the lower part of the reservoir. When the thermometer is then cooled to the actual freezing-point of the benzene the temperature can be read off on the scale. The numbers on the scale obviously do not represent the correct Centigrade temperatures, but merely relative temperatures. If the amount of mercury in the bulb is too small, the temperature is raised until the thread of mercury reaches from the bulb to the reservoir, the thermometer is then inverted, and some of the mercury is gently tapped into the upper part of the reservoir, so that it joins the thread. The temperature is then allowed to fall to within 2 or 3 degrees of the actual freezing-point, care being taken that the mercury thread does not become broken. When the temperature is some 2–3 degrees above the freezing-point of the solvent any excess of mercury attached to the thread is shaken into the lower part of the reservoir by gently tapping, and the instrument is then ready for use.

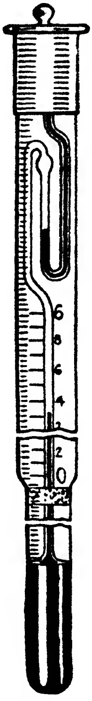


Fig. 73

The same instrument should not be used for very varying temperatures, as the glass after being heated does not immediately assume its original volume on cooling. It is advisable to have one instrument for comparatively low temperatures and a second one for higher temperatures (e.g. boiling-point determinations). Some of the points to be observed in the carrying out of a careful molecular weight determination by the freezing-point method are:

(1) The temperature of the cooling bath should not be more than 3° below the actual freezing-point of the solution.

(2) The liquid, the freezing-point of which is being determined, should not be supercooled more than 0·5°, i.e. the inner tube and air jacket should be removed from the outer vessel when the thermometer registers a temperature a few tenths of a degree below the actual freezing-point. The object of preventing too great a supercooling is to avoid the sudden formation of a large quantity of solid solvent. If this happens, the concentration of the solution alters materially, and the actually observed freezing-point is somewhat too high.

(3) The stirring should be continuous and fairly regular, but

not so rapid that the heat due to friction makes any appreciable difference. The stirring may be a little more rapid just before the liquid freezes, in order to facilitate the separation of solid particles.

(4) The mean of at least four readings should be taken in each case, and solutions of two or three different concentrations should be examined. The usual method is to determine the freezing-point of the solvent, then to introduce a small amount of the solute through the side tube, to see that it is all dissolved, and to determine the freezing-point of the solution. A further amount of solute is added, and the freezing-point of the more concentrated solution determined. The process may be repeated several times. The working limits are: (*a*) lower limit, an amount of substance sufficient to produce a depression of at least 0·1°; (*b*) upper limit, the most concentrated solutions must all be such that, when cooled, crystals of pure solvent and not crystals of the solute separate.

(5) If the solvent is hygroscopic, care should be taken to protect it from moisture or means adopted to keep the moisture content constant. Dry air should be passed in through the side tube or the freezing-point determined in the presence of a salt-pair (e.g. Na_2SO_4, $10H_2O - Na_2SO_4$).*

Experiment 11.—Determine the molecular weight of benzoic acid in (*a*) acetic acid, (*b*) benzene, and in the latter case calculate the degree of association (x) of benzoic acid in benzene solution from the formula,†

$$x = \frac{\Delta_1 - \Delta_2}{\Delta_1\left(1 - \frac{1}{n}\right)},$$

* *Roberts and Bury*, J. C. S. 1923, **123**, 2037.

† This formula is based on the following considerations:

In every gram molecule of substance there will be $1 - x$ gram molecule unassociated and $\frac{x}{n}$ associated. ∴ total number of gram molecules is $1 - x + \frac{x}{n}$, or $1 - x\left(1 - \frac{1}{n}\right)$, but the depression of freezing-point is proportional to the number of gram molecules present in a given volume of solution.

$$\frac{\Delta_2}{\Delta_1} = \frac{1 - x\left(1 - \frac{1}{n}\right)}{1};$$

$$x = \frac{\Delta_1 - \Delta_2}{\Delta_1\left(1 - \frac{1}{n}\right)}.$$

where n represents the number of molecules which associate to form the complex molecule (in this case $n = 2$). Δ_2 = the observed depression for the given solution, Δ_1 the calculated depression if no association had occurred, and x is the fraction of the total number of molecules which combine to form the larger molecules.

3. **Rast's Method.**—The very high value for C in the case of *camphor* makes it possible to use an ordinary melting-point apparatus for the determination of molecular weights if camphor be taken as the solvent. The introduction of known weights of solute into pure camphor causes large depressions of the solidifying (melting) point, and these can be determined sufficiently accurately by the use of thermometers graduated to 0·5° or, better, to 0·1°.

The melting-points of camphor and of mixtures of camphor and solute of known composition are determined in the usual melting-point apparatus with the exception that the capillary tubes used are longer and wider than those normally used for melting-point determinations. The length should be at least 10 cm. and the diameter 2–3 mm., so that the actual process of melting can be carefully followed.

The first operation consists in determining the melting-point of the pure camphor with the thermometer to be used. For this purpose some camphor is powdered and a small amount transferred to one of the capillary tubes and pressed down by means of another and narrower tube, sufficient powder being used to give a column of 1 cm. length. The tube is fixed in the melting-point apparatus and the temperature raised fairly rapidly until the camphor melts to a clear liquid (176°). The temperature is allowed to fall until the camphor resolidifies and is then raised again *very slowly* (1° per minute) until the camphor remelts. The actual reading to be taken is the temperature at which the last trace of solid just disappears. Three consistent determinations should be made.

To determine the molecular weight of a solute the following procedure is adopted. About 0·2 g. of the solute is added to a carefully weighed clean glass tube (6 cm. × 1 cm.) and the whole accurately reweighed. About 2·0 g. of powdered camphor are added and the weighing repeated. The tube is then either sealed or loosely corked (to prevent loss of camphor by volatilization) and heated carefully in a bath until a clear homogeneous liquid is obtained. It is then removed from the

bath and shaken while cooling until the mixture solidifies. The cork is removed or the upper part of the sealed tube broken off without splintering the glass. The solid is removed with the aid of a glass rod flattened at one end, powdered rapidly in a mortar, and the melting-point of a sample taken in exactly the same way as described for pure camphor. It should be repeated with two or three samples and concordant results obtained.

Experiment 12.—Determine the molecular weight of one of the following substances by the Rast method: acetanilide, naphthalene, methyl oxalate, cinnamic acid.

C. Boiling-point Method or Ebulliscopic Method

The principles underlying this method are essentially similar to those for the cryoscopic method. (*a*) For a given pressure the boiling-point of a pure liquid is constant. (*b*) The boiling-point is raised by the introduction of a solute, and for an ordinary solute the raising of the boiling-point is proportional to the amount dissolved in a given weight of solvent. (*c*) For different solutes quantities in the ratio of their molecular weights produce the same raising of the boiling-point. Hence if the molecular raising of the boiling-point is known for a given solvent, the molecular weight of a suitable solute can be determined by means of the formula—

$$M = \frac{Cp}{\Delta},$$

where C is the molecular raising of the boiling-point, p = number of grams of solute in 100 g. of solvent, and Δ is the actual elevation observed.

D. Vapour-pressure Methods

According to Raoult the same generalization holds for the lowering of the vapour pressure of a solvent by the introduction of a solute as for the lowering of the freezing-point or the raising of the boiling-point. Various types of apparatus based on this principle have been suggested, but none has been adopted as a general practical method in the laboratory. The

simplest is probably that described by *Hammick*, School Science Review, 1921, 290; cf. also *Blackman*, J. C. S. 1905, 1474. An interesting micro-method is described by *Barger*, J. C. S. 1904, 286.

IX. HYDROCARBONS

A. Saturated Hydrocarbons or Paraffins, C_nH_{2n+2}

(S.B. Chap. I)

Method I.—The common laboratory method for the preparation of the simpler members of the paraffins is by heating an intimate mixture of the sodium salt of a fatty acid with sodium hydroxide, preferably in the form of soda-lime.

$$C_nH_{2n+1} \cdot \frac{COONa}{H\,ONa} = Na_2CO_3 + C_nH_{2n+2}.$$

Experiment 13.—Methane, CH_4. An intimate mixture of one part, by weight, of **anhydrous** sodium acetate with four parts, by weight, of dry soda-lime is heated in a hard-glass flask or tube provided with a cork and delivery tube. The vessel is heated gently and then more strongly, and the gas evolved is collected in the usual manner in cylinders by means of the pneumatic trough. Special attention is drawn to the following points:

1. The materials must be thoroughly dry, as otherwise water collects and may drop back on to the hot glass vessel and cause it to crack. Crystallized sodium acetate contains three molecules of water of hydration. The simplest method of rendering the crystals anhydrous is to fuse them on a clean sand tray until no more water is given up. The soda-lime, which is somewhat hygroscopic, should also be dried by heating it strongly in a metal dish or tray.

2. As methane and air in certain proportions form explosive mixtures, large quantities of gas should not be collected until the air in the generating flask has been allowed to escape. A small test tube full of gas should be collected from time to time and a light applied; if the gas burns quietly it will indicate that practically all the air has been removed and larger quantities of the gas can be safely collected.

3. The gas evolved in this reaction is not pure, but contains appreciable amounts of hydrogen and ethylene.

Apply a light to a cylinder of the gas. Note what happens and prove that carbon dioxide is formed.

Bubble the gas through bromine water and see whether the colour of the bromine is destroyed. Expose a mixture of methane and chlorine to sunlight and observe what happens.

This method can be used for the preparation of practically all types of hydrocarbons, e.g. saturated, unsaturated and aromatic, from the corresponding carboxylic acids.

Method II.—For the preparation of a pure paraffin a common method is the reduction of an alkyl halide (Chap. XI) with nascent hydrogen, usually from the copper-zinc couple and alcohol.

$$C_nH_{2n+1}I + 2H = C_nH_{2n+2} + HI.$$

Experiment 14.—Ethane,* C_2H_6. Granulated zinc (20 g.) is treated four times with a 2 per cent solution of cupric sulphate, the sulphate being left each time in contact with the zinc until completely decolorized. The zinc, covered with a fine deposit of copper, is washed with water and finally with alcohol, and is then placed in a 200 ml. flask fitted up as shown in fig. 74. 100 ml. of alcohol mixed with a drop or two of dilute sulphuric acid are added, and ethyl iodide, C_2H_5I (Exp. 33), gradually run in from a dropping funnel. The gas evolved often contains ethyl iodide, and it is advisable to pass it through the tube *a*, which contains more of the copper-zinc couple moistened with alcohol.

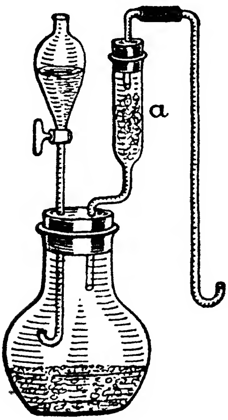


Fig. 74

The method of collection and properties are similar to those of methane.

Method III.—Certain of the lower members of the paraffin series can be prepared by the electrolysis of aqueous solutions of the potassium or sodium salts of fatty acids, e.g. ethane from sodium acetate solution.

The hydrocarbon is evolved at the anode, and is formed

* *Gladstone and Tribe*, J. C. S. 1884, **45**, 154.

when the complex acetate anion $CH_3{\cdot}COO^-$ is discharged. The non-charged group $CH_3{\cdot}COO$ is unstable, and immediately decomposes into CH_3 and CO_2. The CH_3 groups then unite in pairs to form ethane molecules. The gas is not pure.

Experiment 15.—Electrolytic preparation of ethane. A saturated solution of sodium acetate, containing about 2 per cent of glacial acetic acid, is placed in a porous pot (1·5 in. in diameter) closed by a cork through which the anode and delivery tube pass. This anode consists of a stout piece of platinum wire wound in the form of a spiral. A convenient device is to fuse the anode into the T-shaped delivery tube (fig. 75).

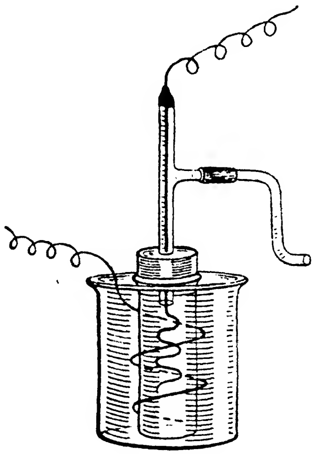


Fig. 75

A piece of nickel wire wound round the cell serves as the cathode. The porous cell is placed in a beaker also containing a saturated solution of sodium acetate, and a current of 60–80 amperes per square decimetre of anode surface is passed.

As the temperature should not rise above 20° the whole apparatus should be placed in a large vessel of cold water. The gas which issues from the delivery tube consists of a mixture of ethane and carbon dioxide, the latter of which can be absorbed by collecting the gas over a fairly concentrated solution of potassium hydroxide. The hydrogen evolved at the cathode is allowed to escape.

Note.—This method does not always give good yields of paraffin hydrocarbons, e.g. when sodium propionate is used the chief product is ethylene and not *n*-butane. This may be due to the reaction of the discharged ethyl radicals with discharged hydroxyl radicals:

$$C_2H_5 + OH \quad CH_2{:}CH_2 + H_2O.$$

The arrangement of apparatus generally used for electrolytic experiments is shown in fig. 76. It consists of a source of current S (accumulator cells are always used) joined in

series with the electrolytic cell B and an ammeter A and regulating resistance (rheostat) R. If an accurate record of *the amount of current which has passed through the circuit* is required, the ampere-hour meter C (generally a copper voltameter) is included, but this can usually be dispensed with. To determine the difference of potential between the electrodes a voltmeter V may be joined in parallel to the electrodes.

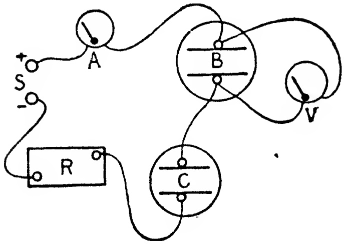


Fig. 76

The following terms require explanation:

Ampere-hours.—This is the product of the number representing the amperes passing the ammeter and the number representing the hours during which the current passes. It provides a measure of the total quantity of electricity which has passed through the circuit.

Current density is the quotient of the current (amperes) passing through the circuit by the area of the electrode measured in square decimetres. It therefore represents the number of amperes per unit area (sq. dm.) of the electrode.

B. Olefine Hydrocarbons, C_nH_{2n}

(S.B. Chap. I, B)

A general method for the preparation of an olefine hydrocarbon is the elimination of water from a saturated monohydric alcohol (Chap. X, A).

$$C_nH_{2n+1}\cdot OH - H_2O = C_nH_{2n}.$$

For the dehydration various reagents can be used. The alcohol vapour can be passed over a catalyst heated to a suitable temperature, e.g. alumina at 400°, or the liquid alcohol can be heated in a distillation apparatus with one of the common dehydrating agents, e.g. concentrated sulphuric acid, phosphoric anhydride, phosphoric acid, zinc chloride or *p*-toluene-sulphonic acid. An interesting catalytic dehydration consists in heating a tertiary, or in a few cases a secondary alcohol with a small amount of iodine.

Experiment 16.—Ethylene, C_2H_4, from ethyl alcohol, $C_2H_5 \cdot OH$. A mixture of 25 g. of ethyl alcohol (rectified spirits), 150 g. of concentrated sulphuric acid, and a small amount of dry sand is placed in a large round-bottom flask (1·5 litre). The object of the sand is to prevent frothing. The flask carries a rubber stopper with two holes; one of these is for the delivery tube, the other for a dropping funnel. The stem of the drop-

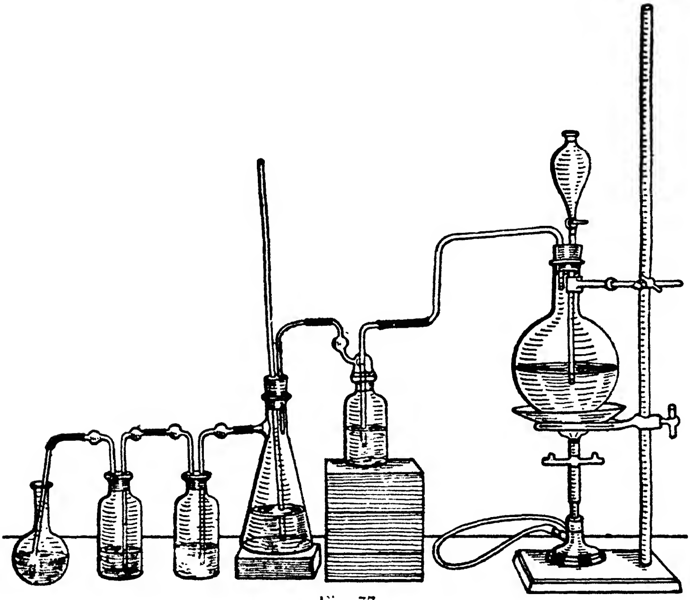


Fig. 77

ping funnel should be drawn out to a fine point and slightly bent. By this device the whole stem can be kept filled with liquid, and the gas evolved will not bubble through the liquid in the funnel. The gas which issues is mixed with alcohol and ether vapour, carbon dioxide, sulphur dioxide, and other gases. It is therefore advisable to pass it through a cold, empty wash bottle in order to collect ether and alcohol vapours, a wash bottle containing concentrated sulphuric acid in order to remove these vapours completely, and finally through a wash bottle containing fairly concentrated potassium hydroxide solution to remove the carbon dioxide and sulphur

dioxide (see fig. 77). The flask is heated on a sand tray until a steady stream of gas is evolved, and then a mixture of one part by weight of alcohol with two of concentrated sulphuric acid is run in slowly from the tap funnel. The gas may be collected over water, in which it is sparingly soluble (1 volume in 4 at 0°).

Examine the gas and see whether it is inflammable, whether it forms an explosive mixture with air, whether it is absorbed by bromine water, whether it reacts readily with chlorine, and whether it is readily oxidized by acidified potassium permanganate: also whether it yields precipitates when bubbled through ammoniacal silver nitrate or cuprous chloride.

N.B.—Whilst the apparatus for the preparation of ethylene is fitted up, it will be an advantage to proceed with the preparation of ethylene dibromide (Exp. 48, Chap. XI, E).

In the above experiment the sulphuric acid may be replaced with advantage by a concentrated solution of orthophosphoric acid * (sp. gr. 1·75).

Experiment 17.—Propylene, C_3H_6, from isopropyl alcohol, $(CH_3)_2CH{\cdot}OH$.†

A 200 ml. distilling flask (with side tube) is fitted with a stopper carrying a thermometer and a dropping funnel, the stem of which is drawn out to a fine point, both so arranged as to reach nearly to the bottom of the flask. 60 ml. of syrupy orthophosphoric acid (sp. gr. 1·75) are placed in the flask and heated by means of a small flame until a temperature of 210° is registered by the thermometer. Isopropyl alcohol is then run in very slowly by means of the dropping funnel, care being taken to moderate the action.

The gas is passed through a wash bottle surrounded by ice or a freezing mixture in order to condense water, alcohol, and ether vapours. At a temperature of 200–220° a supply of gas at the rate of 10–15 litres per hour can be kept up. As the reaction is continuous, practically unlimited amounts of isopropyl alcohol can be decomposed by a relatively small amount of phosphoric acid.

Experiment 18.—Amylene, C_5H_{10}, from amyl alcohol, $C_5H_{11}{\cdot}OH$.‡

An amylene boiling at 35–38° can be obtained by mixing amyl alcohol (from fusel oil) (1 part) with anhydrous zinc chloride

* *Newth*, P. 1901, **17**, 147. † *Newth*, J. C. S. 1901, 917.
‡ *Würtz*, A. 1863, **128**, 225.

(1·5 part) in the form of small lumps, leaving for twenty-four hours, then heating on a sand tray, collecting the low boiling distillate, and carefully fractionating. The product is a mixture of several isomeric amylenes, but consists mainly of trimethyl-ethylene $(CH_3)_2{:}C{:}CH\cdot CH_3$. Compare the chemical properties of amylene with those of ethylene.

See also Grignard's synthesis, Chap. XXIX, E.

Isomeric with the olefines are the polymethylenes or cyclic paraffins, e.g. cyclo-pentane, C_5H_{10}, and cyclo-hexane, C_6H_{12}. In chemical properties they resemble the paraffins more than the olefines (cf. S.B. Chap. XVI).

C. Acetylene Hydrocarbons, C_nH_{2n-2}

(S.B. Chap. I, C, and LI, F)

A general method for the preparation of an acetylene hydrocarbon is by the elimination of two molecules of hydrogen bromide from one molecule of an olefine dibromide, e.g. ethylene dibromide, under the influence of an alkali:

$$\begin{array}{ccc} Br & & H \\ H- & C\cdot C & -H \\ H & & Br \end{array} - 2HBr = H\cdot C\vdots C\cdot H.$$

As a rule, the first molecule of hydrogen bromide is eliminated more readily than the second, and thus in the above-mentioned example vinyl bromide, $CH_2{:}CHBr$ is formed as a by-product. The best yields of hydrocarbon are obtained when sodium ethoxide, $C_2H_5\cdot ONa$, is used.

Experiment 19.—Acetylene, C_2H_2, from ethylene dibromide, $C_2H_4Br_2$.

10 g. of metallic sodium are dissolved in 100 g. of ethyl alcohol, contained in a round-bottom flask, the metal being added gradually in the form of thin strips. When most of the sodium has been added it may be necessary to heat the alcohol. The flask is then provided with a cork carrying a dropping funnel and reflux condenser, e.g. a small Soxhlet condenser (fig. 18). The dropping funnel should be drawn out to a fine point, and contain 20 g. of ethylene dibromide (Exp. 48). The upper end of the condenser is connected by a glass tube to two wash bottles containing a small amount of ethyl alcohol and surrounded by a freezing mixture of ice and

salt. The contents of the flask are heated on a sand tray or in a boiling bath of salt and water, and the ethylene dibromide is dropped in gradually. The gas which issues from the second wash bottle is tested from time to time until all the air has been removed, when it can be collected in cylinders or in a gasholder. The gas is somewhat soluble in water, but is less soluble in a saturated solution of common salt.

Experiment 20.—Acetylene from calcium carbide, CaC_2.

Several metallic carbides when brought into contact with water generate acetylene. The commonest of these carbides is calcium carbide. Water is gradually added by means of a tap funnel to pieces of calcium carbide placed in a flask provided with a cork with two holes. This cork carries the tap funnel and also the delivery tube. The rate at which the gas is evolved can be regulated by the quantity of water added. The air should be displaced before cylinders of the gas are collected. The gas prepared by this method will differ somewhat in properties from the gas prepared by the previous method, as it contains small amounts of impurities, especially hydrogen sulphide and phosphide.

The following properties should be examined:

1. Inflammability and nature of flame.
2. Its instability and decomposition by electric sparks.
3. Ready decolorization of bromine solutions. A small amount of acetylene tetrabromide, $C_2H_2Br_4$, can be prepared by slowly bubbling the gas through bromine (see Preparation of ethylene dibromide, Exp. 48). After washing with sodium hydroxide solution and water, and subsequent drying with calcium chloride, it forms a heavy oil, $D_{4^\circ}^{17^\circ}$ 2·971, and b.p. 114° under 12 mm. pressure.
4. Oxidation with acidified permanganate.
5. Formation of solid silver and cuprous derivatives when passed through small amounts of ammoniacal silver nitrate and cuprous chloride solutions. *N.B.*—These precipitates will be discoloured when they are obtained from impure acetylene. Only small amounts should be prepared, as in the dry state they are extremely explosive.

Isomeric with the acetylenes are the **dienes**, i.e. hydrocarbons containing two olefine linkages, the most interesting being those containing conjugated linkages, cf. preparation of phenylbutadiene, $C_6H_5{\cdot}CH{:}CH{\cdot}CH{:}CH_2$ (Exp. 288).

D. Hydrocarbons, C_nH_{2n-4}

The terpenes, $C_{10}H_{16}$, are of this type. They may be open-chain compounds with 3 olefine links, e.g. myrcene, single-ring compounds with two double bonds, either in the ring or a side chain, e.g. dipentene, or bicyclic with one olefine link, e.g. pinene (cf. S.B. Chap. LVII). The commonest terpene is α-pinene (b.p. 156°) which is readily obtained by fractionation of American oil of turpentine.

E. Benzene Hydrocarbons, C_nH_{2n-6}

(S.B. Chap. XVIII)

Many of these are prepared from coal tar by processes of fractional distillation. For the preparation of pure benzene from commercial 50 per cent benzol see Exp. 2.

Three methods for synthesising homologues of benzene are used:

1. **The Fittig Synthesis.***—This consists in subjecting a mixture of an alkyl halide and a halogen derivative of a benzene hydrocarbon to the action of metallic sodium in the presence of dry ether:

$$\begin{array}{l} C_2H_5\vdots Br + Br\vdots C_6H_5 = 2NaBr + C_6H_5\cdot C_2H_5. \\ \qquad\ \ \vdots Na \quad Na\vdots \end{array}$$

Experiment 21.—Ethylbenzene, $C_6H_5\cdot C_2H_5$, from ethyl iodide and monobromo-benzene.

24 g. of metallic sodium (this is an excess) in the form of thin sheets are added to 100 ml. of pure dry ether † contained in a ½-litre round-bottom flask provided with a long reflux condenser, preferably a double-surface condenser, which is finally closed with a calcium chloride tube (fig. 81). 50 g. of monobromo-benzene (Exp. 37), and somewhat more than an equivalent quantity of ethyl iodide, viz. 55 g., are added, and the mixture left overnight. (*N.B.*—The water should not be allowed to run through the condenser during the night.) Next morning the liquid is removed from the blue solid which has been formed. The latter is washed twice with small amounts of dry ether, and these washings are added to the main bulk

* *Tollens and Fittig*, A. 1864, **131**, 303.

† For purification see Exp. 29.

of liquid. The solid consists of a mixture of sodium bromide and iodide and unaltered sodium, and should be transferred to a dish and added in small quantities to a large vessel of cold water. *Do not* tip the whole mass of solid from the flask into water, as a vigorous action will occur and a serious explosion and fire may result.

The liquid which was poured off from the solid is distilled from a steam bath or water bath heated by steam (see Precautions, Introduction). After the ether has been removed the residue is fractionated from a small distilling flask without the aid of a fractionating column, and the portion boiling at 133–135° collected separately. Yield 60 per cent of theoretical, viz. 20 g. B.p., 135°.

2. **Friedel and Craft's Synthesis.**—This is similar to the synthesis of a ketone described in Exp. 213, except that an alkyl chloride or iodide is used in place of the acid chloride (see also Exp. 305*a*).

3. **Grignard's Synthesis.**—See Exp. 301.

4. **Clemmensen's Reaction.**—Many aldehydes and ketones can be reduced to the corresponding hydrocarbons by reduction with amalgamated zinc and concentrated hydrochloric acid, e.g. acetophenone yields ethylbenzene (Exp. 261) and anthraquinone gives reduced anthracene derivatives (Exp. 262).

Polycyclic Hydrocarbons.—Related to benzene are the two important hydrocarbons, naphthalene and anthracene, which are commercial products obtained from coal tar. These form valuable derivatives, the preparation of some of which is described in Chaps. XVI, XVII and XXX.

F. Examination of a Liquid Hydrocarbon

The group to which an unknown hydrocarbon belongs can often be determined by an examination of some of its chemical properties. Some of the more important of these are:

1. The manner in which the hydrocarbon burns, e.g. non-luminous, luminous, or smoky flame. All benzene hydrocarbons burn with an extremely smoky flame, all the lower paraffins with a non-luminous or luminous but non-smoky flame.

2. Behaviour towards bromine. Most olefine and acetylene hydrocarbons readily decolorize a solution of bromine in water or in chloroform. Paraffins and benzene hydrocarbons do not.

3. Olefines and acetylene hydrocarbons are readily oxidized by acidified permanganate, and hence decolorize a dilute acidified solution of this reagent when added to or bubbled through the solution. Paraffins and also benzene hydrocarbons, unless they contain a double bond in the side chain, e.g. styrene, $C_6H_5 \cdot CH:CH_2$, will not readily decolorize permanganate.

4. Formation of explosive metallic derivatives. This reaction is characteristic of acetylene and its monoalkyl derivatives, but is not given by dialkyl derivatives of acetylene, e.g. $CH_3 \cdot C \vdots C \cdot CH_3$.

5. Formation of nitro-derivatives and sulphonic acids is characteristic of benzene derivatives. Thus if the hydrocarbon dissolves in concentrated nitric acid or a mixture of concentrated nitric and sulphuric acids, and the solution when poured into water yields a yellow oil or solid, it may be safely concluded that the hydrocarbon is aromatic.

6. Most aromatic hydrocarbons, especially the polynuclear ones, form definite additive compounds with picric acid or trinitrobenzene, and such compounds are frequently used for characterizing particular hydrocarbons (cf. Table I, Chap. XXXVIII).

X. ALCOHOLS AND ETHERS

A. Monohydric Alcohols

(S.B. Chap. III, A)

1. **Saturated Alcohols.**—*Method I.*—Several alcohols can be obtained by the action of micro-organisms on sugars. The most important example is the fermentation of cane sugar by ordinary brewers' yeast.

(*a*) Inversion, $\underset{\text{Cane sugar}}{C_{12}H_{22}O_{11}} + H_2O \rightarrow \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Fructose}}{C_6H_{12}O_6}$;

(*b*) Fermentation, $C_6H_{12}O_6 \rightarrow \underset{\text{Ethyl alcohol}}{2C_2H_6O} + 2CO_2$.

400 g. of cane sugar are dissolved in 2 litres of water, and the solution placed in a Winchester quart bottle. 30 g. of brewers' yeast made up to a paste with a small quantity of water are added, and the loosely stoppered bottle is allowed to stand in a warm place for one or two days. The tempera-

ture most favourable for fermentation is between 25° and 30°. The liquid is then distilled in portions of about 500 ml. at a time from a large distilling flask (1 litre) provided with a long neck. The side tube is connected to a water condenser and receiver. Some pieces of porous pot are added to prevent bumping, and the heating is conducted regularly on a sand bath. About one-third of the contents of the flask is distilled over and collected in each case. The united distillates, the total volume of which should be about 700 ml., are again subjected to fractional distillation from a litre flask fitted with a rod and disc fractionating column (fig. 4*a*) (observe precautions described under Fractional Distillation, Chap. I, B), the distillation being continued until the thermometer registers a temperature of 80°. The product is placed in a 500 ml. distilling flask, and about 100 g. of quicklime added in the form of small lumps. The flask is fitted to a condenser and receiver and allowed to stand overnight. In the morning the alcohol is distilled off from the residue of partially slaked lime by heating the flask in a paraffin or metal bath.

Determine the density of the product by means of a pyknometer (figs. 31, 32, 33). From this result determine the percentage of alcohol in the liquid by consulting tables of specific gravities of mixtures of alcohol and water. Hence calculate the yield of alcohol in the above experiment.

The alcohol obtained in this manner is not anhydrous. Ordinary absolute alcohol contains about 0·2 per cent of water.

Experiment 23.—To remove the last traces of water from ethyl alcohol. Commercial absolute alcohol (99·8 per cent) is treated in a reflux apparatus (fig. 80) with about 1 per cent of its weight of metallic calcium in the form of freshly prepared turnings. The condenser is fitted with a calcium chloride tube to prevent access of moisture, and the mixture is kept vigorously boiling on a water bath until the solid deposit in the flask, which is at first dark-coloured, becomes practically white. The alcohol is then distilled over into a dry receiver, which is protected from access of moisture by a calcium chloride tube. The portion passing over at a constant temperature is collected and treated again in a similar manner with a smaller quantity of calcium turnings (0·5 per cent). The solid formed in this case should be white, and on distillation the alcohol should pass over at constant temperature. It is finally distilled with a small amount of *p*-toluene-sulphonic acid in order to remove

traces of ammonia formed from calcium nitride on the metallic calcium.

Methyl alcohol is purified in a similar manner.

Physical Properties of Ethyl Alcohol.—A colourless mobile liquid with spirituous odour. B.p. 78·3° under 760 mm., 13° under 21 mm.; solidifies at −112·3°; $D_{4°}^{15°}$, 0·790. It is extremely hygroscopic; contraction takes place on mixing with water, and heat is developed.

Physical Properties of Methyl Alcohol.—A colourless liquid. B.p. 66°; $D_{4°}^{15·5°}$, 0·7952.

Method II.—A very common method for the preparation of an alcohol is by the replacement of halogen by hydroxyl. This is usually effected by means of an aqueous solution of an alkali (e.g. potassium hydroxide or carbonate), or by means of metallic oxides (e.g. plumbous or silver oxides) and water.

In a similar manner practically any ester yields an alcohol on hydrolysis.

Experiment 24.—Benzyl alcohol from benzyl chloride.

$$2C_6H_5CH_2Cl + H_2O + K_2CO_3 = 2C_6H_5CH_2OH + 2KCl + CO_2.$$

10 g. of benzyl chloride are boiled in a reflux apparatus (fig. 81, without calcium chloride tube) with about one and a half times the theoretical weight of potassium carbonate dissolved in 100 ml. of water, until the smell of benzyl chloride has disappeared. About six hours will be necessary. The liquid is extracted with ether (Chap. I, A), the ethereal extract dried by standing over anhydrous potassium carbonate, and then decanted into a small distilling flask, and the ether removed by distillation (cf. General Precautions). The residue is fractionated from the same flask, the water condenser being replaced by a short air condenser (fig. 3) and the portion boiling between 200° and 210° collected separately. Yield 5–6 g.

Physical Properties.—A colourless liquid with an aromatic odour, b.p. 206·5°; $D_{4°}^{0°}$, 1·0628. It is only sparingly soluble in water, but is miscible in all proportions with alcohol and ether.

Method III.—Primary alcohols result from the reduction of aldehydes (Chap. XXI), while ketones (ibid.) yield secondary alcohols such as

$$CH_3{\cdot}CH{:}O + 2H \rightarrow CH_3{\cdot}CH_2{\cdot}OH$$

$$\begin{matrix}CH_3\diagdown\\ \end{matrix}C{:}O + 2H \rightarrow \begin{matrix}CH_3\diagdown\\ \end{matrix}CH{\cdot}OH.$$
$$CH_3\diagup \qquad\qquad CH_3\diagup$$

In the case of the aromatic aldehydes the reduction of a molecule of aldehyde takes place simultaneously with the oxidation of a second molecule, when the aldehyde is shaken with potassium hydroxide solution (*Cannizaro's reaction* *). This is the best method for obtaining furoic acid, $C_4H_3O(CO_2H)$, from commercial furfuraldehyde † and the details are the same as those given in Exp. 25.

Experiment 25.—Benzyl alcohol, $C_6H_5{\cdot}CH_2{\cdot}OH$, **and benzoic acid,** $C_6H_5{\cdot}CO_2H$, **from benzaldehyde.**

$$2C_6H_5{\cdot}CH{:}O + KOH \rightarrow C_6H_5{\cdot}CH_2{\cdot}OH + C_6H_5{\cdot}CO_2K.$$

20 g. of benzaldehyde (Exp. 203) are added to a solution of 18 g. of potassium hydroxide in 12 ml. of water in a thick-walled bottle closed with a cork (*not* a glass stopper), and the mixture shaken vigorously until a permanent emulsion is formed. It is then allowed to stand overnight, when a thick precipitate of potassium benzoate separates out. The mixture is treated with water and shaken until a clear solution is obtained, and is then extracted with ether at least *three* times. The ethereal solution of benzyl alcohol is dried over anhydrous potassium carbonate, then poured into a distilling flask and fractionated. After the removal of the ether the water condenser is replaced by an air condenser, and the fraction which distils at 200–210° collected separately. Yield 8–9 g.; b.p. 206·5°.

The alkaline liquid left after extraction with ether is acidified with moderately concentrated hydrochloric acid. When cold, the precipitated benzoic acid is separated by means of a porcelain funnel and suction pump, washed with water, and dried on a porous plate. It is recrystallized from hot water or purified by sublimation (cf. Chap. I, E). Yield 8–10 g.; m.p. 121°.

Method IV.—Grignard's synthesis (*a*) of secondary alcohols (Chap. XXIX, C), (*b*) of tertiary alcohols (Chap. XXIX, D).

2. **Unsaturated Alcohols.** — These may be prepared by methods analogous to those mentioned above. They may also result from the decomposition of saturated poly-hydroxy-derivatives.

Experiment 26.—Allyl alcohol from glycerol.‡

Glycerol, when heated with formic or oxalic acids, yields

* B. 1881, **14**, 2394. † Org. Syn. **6**, 44

‡ *Tollens and Henninger*, A. 1870, **156**, 153.

glyceryl monoformate, and this decomposes at 220°, yielding allyl alcohol, carbon dioxide, and water.

CH_2OH		CH_2OH		CH_2OH
$CHOH$	$\rightarrow$	$CH \cdot OH$	$\rightarrow$	CH
CH_2OH		$CH_2 \cdot O \cdot CO \cdot H$		CH_2
Glycerol		Glyceryl monoformate		Allyl alcohol

A mixture of 200 g. of glycerol, 50 g. of oxalic acid crystals, and 0·5 g. of ammonium chloride or sulphate, is heated in a large distilling flask attached to a condenser and receiver. A thermometer fixed through the neck of the flask dips *into* the liquid. At first, rapid evolution of carbon dioxide gas occurs, and the temperature indicated by the thermometer remains stationary for a while at 130°. After some time the evolution of gas slackens and the temperature rises gradually to 195°, when evolution of gas practically ceases. At 205–210° gas begins to be evolved again, oily drops appear in the condenser tube, and the disagreeable odour of allyl formate may be detected. The heating is continued carefully, the temperature remaining at 220–230° for some time; later it rises gradually to 260°, when the heating is discontinued.

The distillate which passes over above 220° is a mixture of allyl alcohol with water; some allyl formate, glycerol, and acrolein are also present.

The residue in the flask consists mainly of unchanged glycerol, and should be treated with more oxalic acid (40 g.), and the distillation repeated.

The product is redistilled from a small distilling flask fitted with a thermometer, the process being continued until a test portion of the liquid passing over no longer yields an oily layer on treatment with solid potassium carbonate. This occurs when the thermometer indicates a temperature of 105°. The distillate is treated with solid potassium carbonate, and the allyl alcohol separates out as an oil, which is removed from the aqueous liquid by means of a tap funnel. The oil is treated with more anhydrous potassium carbonate and, after standing for a short time, decanted into a small distilling flask and redistilled. The portion boiling between 92° and 96° is collected separately. Yield about 15 g.

It is a colourless, mobile, oily liquid with a pungent odour. B.p. 96–97°; D^{25°, 0·854.

B. Polyhydric Alcohols

The polyhydric alcohols, compounds containing two or more hydroxyl groups—usually only one attached to any one carbon atom—may be prepared by methods similar to those used for monohydric alcohols. Some of these are:

1. *Saponification of esters*. This method is used on the commercial scale for the production of glycerol $OH{\cdot}CH_2{\cdot}CH(OH){\cdot}CH_2{\cdot}OH$ and fatty acids or their sodium salts. Glycerol is contained in the aqueous liquor after the removal of the fatty acids in Exp. 65.

2. By the replacement of halogen by hydroxyl as in the formation of glycol $OH{\cdot}CH_2{\cdot}CH_2{\cdot}OH$ from ethylene dibromide.

3. By the reduction of the corresponding aldehyde. This is of particular value in the cases of polyhydroxy—aldehydes or their cyclic isomers, the aldoses and ketoses, e.g. the reduction of *d*-glucose to sorbitol by sodium amalgam and water.

Experiment 27.—Glycol from ethylene dibromide.

The reaction is carried out in two stages: (1) The conversion of the dibromide into the diacetate; (2) the alcoholysis of the diacetate to glycol and methyl acetate.

$$CH_3{\cdot}CO{\cdot}O{\cdot}CH_2{\cdot}CH_2{\cdot}O{\cdot}CO{\cdot}CH_3 + 2CH_3OH \rightarrow OH{\cdot}CH_2{\cdot}CH_2{\cdot}OH + 2CH_3{\cdot}CO{\cdot}OCH_3.$$

1. **Preparation of Diacetylglycol.**—A mixture of ethylene dibromide (50 g.), glacial acetic acid (17 g.), and finely powdered dry potassium acetate (50 g.) is placed in a distillation flask (0·5 litre) fitted with reflux condenser and tilted so that the side tube of the flask is inclined upwards. The mixture is heated so that brisk ebullition takes place. After two hours the product is distilled—care being taken that a large smoky flame is used and kept moving. The distillate is heated with another 50 g. of the dibromide and 70 g. of potassium acetate for 2–3 hours and again distilled. The distillate is now fractionally distilled, using a short fractionating column (10 ml.), and after 2 or 3 fractionations the diacetate is obtained boiling at 180–190°. The yield is about 80 per cent.

2. **Preparation of Glycol.**—The diacetyl compound (50 g.) is boiled for half an hour in a 200-ml. flask, fitted with a reflux condenser, with 60 ml. of a 3 per cent solution of hydrogen chloride in pure methyl alcohol (fig. 81). The condenser is

then turned down (fig. 78) and the methyl acetate and unused methyl alcohol distilled off. After cooling, the product is shaken with dry ether which extracts any remaining diacetate. The glycol, which is insoluble in ether, forms the lower layer and after separation is distilled. B.p. 195°; yield 80–90 per cent.

C. Recognition of Alcohols

(*a*) **General Reactions.**—(Apply these tests to absolute ethyl alcohol.) *

(i) Alcohols react with metallic sodium, with evolution of hydrogen and formation of alcoholates.

$$2C_2H_5{\cdot}OH + 2Na \rightarrow 2C_2H_5{\cdot}ONa + H_2.$$

(ii) They react vigorously with phosphorus halides (e.g. phosphorus pentachloride), with the production of halogen derivatives and evolution of hydrogen halide.

$$C_2H_5{\cdot}OH + PCl_5 \rightarrow C_2H_5Cl + POCl_3 + HCl.$$

(See also Exp. 32.)

(iii) With acyl chlorides they react with the formation of fragrant-smelling esters. For this purpose use a benzene solution of acetyl chloride. (See Exp. 90.)

(*b*) **Tests for Unsaturated Alcohols.**—(Apply to allyl alcohol.)

(i) They decolorize bromine water.

(ii) They are oxidized by acidified potassium permanganate solution.

(*c*) The specific alcohols can be identified by means of their physical constants, or by the preparation of some solid derivative whose melting-point can be taken.

As the acetyl and benzoyl derivatives of aliphatic alcohols are liquids, it is usual to prepare the 3:5-dinitrobenzoate esters by using 3:5-dinitrobenzoyl chloride. For the melting-points of these dinitrobenzoates, cf. Tables IV–V.

Special Tests for Methyl Alcohol, CH_3OH.—Warm a little of the alcohol with 3:5-dinitrobenzoyl chloride. A solid ester is produced. Recrystallize from alcohol, and determine the melting-point of the dried crystals. M.p. 107°. If appreciable amounts of water are present, either dehydrate before warming

* The presence of small amounts of water in many organic liquids will produce similar reactions.

with the acyl chloride or use the *Schotten-Baumann method* (Exp. 178).

Test for Methyl Alcohol when in dilute solution.—A test for small amounts of methyl alcohol is based on its oxidation to formaldehyde. The liquid to be tested is fractionally distilled and the lowest boiling fraction taken. 0·1 g. of chromic acid (or potassium dichromate) and 10 drops of concentrated sulphuric acid are added to 5 ml. of the liquid. As soon as the mixture becomes green, 6 drops of it are placed in a porcelain dish and 20 drops of concentrated sulphuric acid and a little morphine are added. Traces of methyl alcohol or formaldehyde can be recognized by the appearance of a deep yellowish-brown colour, small amounts by a deep crimson-red colour, and large amounts by a deep violet colour. In place of morphine, a few drops of a freshly prepared solution of pyrogallol (0·5 : 10) may be used. If much methyl alcohol is present, a chocolate-brown colour is produced.

Special Tests for Ethyl Alcohol, C_2H_5OH.—(i) The characteristic odour of ethyl acetate may be detected when the alcohol is warmed with concentrated sulphuric acid and an acetate (see Exp. 85).

(ii) With 3:5-dinitro-benzoyl chloride it yields a solid ester. M.p. 92°.

(iii) The iodoform test. Add a little solution of iodine in aqueous potassium iodide solution to an aqueous solution of ethyl alcohol. Then add potassium hydroxide solution drop by drop until the colour of iodine just disappears. Warm in a water bath to about 80° and then cool. A yellow crystalline precipitate of iodoform is produced. If the alcohol solution is very dilute, the formation of the precipitate will take some time; in any case the characteristic odour of iodoform will be detected.

Note.—This test is also given by certain other substances, e.g. acetone, acetaldehyde, and isopropyl alcohol, but *not* by methyl alcohol.

D. Ethers or Alkyl Oxides, R·O·R, or R·O·R′
(S.B. Chap. IV, A)

The ethers are the anhydrides of the alcohols.

One of the commonest methods for the preparation of ethers is by the action of concentrated sulphuric acid on a

monohydric alcohol. The reaction proceeds in two stages, as represented by the equations:

$$C_2H_5OH + \begin{matrix}HO\\HO\end{matrix}\!>SO_2 \rightarrow \underset{\text{Ethyl hydrogen sulphate}}{\begin{matrix}C_2H\cdot O\\HO\end{matrix}\!>SO_2} + H_2O$$

$$OH\cdot SO_2\cdot OC_2H_5 + C_2H_5\cdot OH \rightarrow \underset{\text{Ethyl ether}}{(C_2H_5)_2O} + SO_2(OH)_2$$

When a mixture of alcohols is used a certain amount of a mixed ether, e.g. $C_2H_5\cdot O\cdot C_3H_7$ (ethyl propyl ether) is formed.

Experiment 28.—Ethyl ether from ethyl alcohol.

100 g. of concentrated sulphuric acid are gradually added to a similar weight of ethyl alcohol (rectified spirit 96 per cent), with constant shaking and cooling. The mixture is placed in a 500 ml. distilling flask fitted with a two-holed cork. Through one hole passes the stem of a dropping funnel, which has been drawn out to a fine point, and which dips below the surface of the liquid; through the other hole a thermometer is fixed, the bulb of which should also be immersed in the liquid. The side tube of the distilling flask is attached to a very long condenser through which a rapid stream of water is flowing. The flask is heated on a sand bath. When the temperature reaches 140° ether begins to distil over, and alcohol is then added through the tap funnel at about the same rate as the distillate passes over. The flame is adjusted so that the temperature is maintained at 140°, and the reaction should be continued until about 200 ml. of alcohol have been added.

Since the vapour of ether is heavy and very inflammable, it is advisable to stretch a damp cloth across the working bench, between the flame and the receiver.

The distillate contains alcohol, water, carbon dioxide, and sulphur dioxide in addition to ether. It is purified by shaking in a separating funnel with a little dilute potassium hydroxide solution. After separation into two layers, the lower aqueous layer is run off, and the ether shaken with about 50 ml. of saturated common salt solution (see p. 3). After running off the latter, the ether is allowed to stand for some time (overnight is desirable) in a distilling flask with granular calcium chloride. It is then redistilled from a previously warmed water bath or steam bath (cf. Precautions), when the whole should pass over between 34° and 35°.

Physical Properties.—A colourless liquid with a characteristic odour; b.p. 35°; $D_{4°}^{15°}$, 0·720. Slightly soluble in water (1 part in 12 of water at 15°), less soluble in salt solution.

Experiment 29.—Purification of ether. In many cases where ether is used as a solvent it is necessary that it should be entirely freed from traces of water and alcohol. For this purpose the ether should be shaken several times with *small* amounts of water in order to remove alcohol. It is then placed in a thick, well-stoppered bottle with a large quantity of *freshly fused* calcium chloride and allowed to stand overnight. It is then filtered through a folded filter paper into another similar bottle also thoroughly dried (see General Precautions), and allowed to stand over metallic sodium. Small amounts of the metal are added from time to time in the form of wire from a sodium press (fig. 98), until no further evolution of hydrogen occurs. When required for use the necessary amount is poured into a dry distilling flask and distilled over phosphorus pentoxide.

(For Phenolic Ethers see Chap. XVII, C.)

Chemical Characteristics of Ethers (S.B. Chap. IV, A).

The ethers are neutral, inert liquids, which when quite dry do not react with sodium, phosphorus pentachloride, or acyl chlorides (cf. alcohols), and are not acted upon by the ordinary reagents for aldehydes and ketones (see Chap. XXI, A2, B2). They are only hydrolysed with difficulty. When saturated with hydrogen iodide gas at 0° they yield alcohol and alkyl iodide (see Chap. XVII, G), and when heated with 3:5-dinitrobenzoyl chloride they yield alkyl chlorides and alkyl dinitrobenzoates.

XI. HALOGEN DERIVATIVES

A. Replacement of Hydroxyl by Halogen

Method I.—By the action of the halogen hydrides on alcohols (S.B. Chap. II).

$$C_nH_{2n+1}OH + HBr \rightleftharpoons C_nH_{2n+1}Br + H_2O.$$

As the reaction is reversible, it is necessary to remove one of the products from the sphere of action as soon as formed.

This is effected by absorbing the water by means of dehydrating agents.

Experiment 30.—Ethyl bromide, C_2H_5Br, from ethyl alcohol.

$$KBr + H_2SO_4 = KHSO_4 + HBr$$
$$C_2H_5OH + HBr = C_2H_5Br + H_2O$$

To obtain a good yield of the product in this preparation it is advisable to use rather more sulphuric acid and alcohol than is required by the equations.

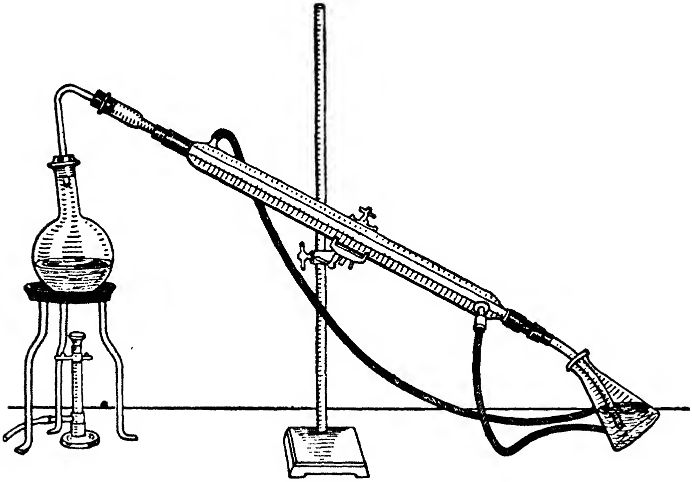


Fig. 78

120 g. of concentrated sulphuric acid are placed in a round-bottomed flask of about 750 ml. capacity, and 50 g. of alcohol (rectified spirit about 95 per cent) added gradually with constant shaking and cooling. 60 g. of powdered potassium bromide are then added, the flask connected with a condenser through which a rapid stream of water is flowing, and the open end of the condenser fitted with an adapter which dips under ice-cold water in a flask. (See fig. 78.) The mixture is heated quickly on a sand bath, frothing occurs during the reaction, and the ethyl bromide passes over and collects as a heavy oily layer at the bottom of the water in the receiver. The distillation is continued till no more oily drops pass over.

The oil is freed from the aqueous layer by means of a separating funnel; it is washed by shaking with its own volume of water, again separated, and then shaken with dilute sodium carbonate solution. During the latter operation the separating funnel should be inverted and the stopcock remain open. After another washing the ethyl bromide is dried by allowing to stand over a small quantity of granular calcium chloride until the liquid becomes clear. It is then decanted into a distilling flask and distilled in the ordinary manner. It is a colourless liquid, b.p. 39°; $D^{13°}$, 1·470. Yield about 40 g., i.e. 80 per cent on the amount of bromide taken.

The above reaction is applicable not only to alcohols of the aliphatic series but also to those of the aromatic series, e.g.:

$$\underset{\text{Benzyl alcohol}}{C_6H_5CH_2OH} + HCl \rightleftharpoons \underset{\text{Benzyl chloride}}{C_6H_5CH_2Cl} + H_2O.$$

All alcohols react with fairly concentrated hydrobromic and hydriodic acid, giving fairly good yields of the corresponding alkyl halides even in the absence of dehydrating agents, provided an excess of acid (3–4 equivalents) is used. The reaction takes place most readily with tertiary alcohols and least readily with primary. Hydrochloric acid does not give good yields of chlorides with primary alcohols.

Experiment 31.—Allyl bromide from allyl alcohol.*

A mixture of 25 g. of allyl alcohol and 300 g. of hydrobromic acid (= 4 mols), of constant b.p. 126°, and sp. gr. 1·49, are gradually heated in a distillation flask or retort connected with a condenser. The heating is continued until no more oily drops pass over. The distillate is then washed, dried, and distilled as in Exp. 30. Yield, 86 per cent. B.p. 70°. Only a small portion of the acid distils over, and if the residue left in the flask is slowly distilled the excess of hydrobromic can be obtained in the form of the solution of constant boiling-point, and may be used for subsequent experiments.

The halogen hydrides, especially hydrogen chloride and bromide, also react with many di- and poly-hydroxy-alcohols.

The number of hydroxyl groups replaced depends on the conditions under which the experiments are conducted, e.g. the temperature, concentration of acid, &c. Thus the final pro-

* *Norris*, Am. 1907, **38**, 640. Compare also *Taboury*, Bull. 1911, [iv], **9**, 124.

duct of the action of hydrogen chloride on glycerol is unsymmetrical dichlorhydrin (Berthelot).

$$\begin{array}{l} CH_2OH \\ \dot{C}HOH \\ \dot{C}H_2OH \end{array} + 2HCl \rightarrow \begin{array}{l} CH_2OH \\ \dot{C}HCl \\ \dot{C}H_2Cl \end{array} + 2H_2O$$

Hydriodic acid acts in a somewhat different manner, causing reduction as well as substitution. By acting on glycerol with this acid *iso*-propyl iodide is obtained.

$$\begin{array}{l} CH_2OH \\ \dot{C}HOH \\ \dot{C}H_2OH \end{array} + \xrightarrow{3HI} \begin{array}{l} CH_2I \\ \dot{C}HI \\ \dot{C}H_2I \end{array} + \xrightarrow{2HI} \begin{array}{l} CH_3 \\ \dot{C}HI \\ \dot{C}H_3 \end{array}$$

Experiment 32.—*iso*-Propyl iodide, $CH_3{\cdot}CHI{\cdot}CH_3$.*

In this case the reaction is carried out by the action of phosphorus tri-iodide and water on the hydroxy-compound.

20 g. of glycerol diluted with an equal volume of water are mixed with 30 g. of iodine in a retort attached to a condenser. 5·5 g. of yellow phosphorus (*Precautions*: Cut into small pieces and weigh under water; do not touch with the hands) are added little by little. Each piece of phosphorus reacts vigorously immediately it is introduced, and produces flashes of light. The iodine dissolves completely if the retort is shaken vigorously after the addition of about one-third of the phosphorus, and the remainder may then be added more quickly. The contents of the retort are distilled until no more oily drops pass over and the distillate is replaced in the retort and redistilled. The product of the second distillation is washed with water, then with dilute sodium hydroxide solution, again with water, dried over granular calcium chloride and redistilled. It forms a colourless liquid; b.p. 89°; $D^{0°}$, 1·744. Yield, 12–15 g.

Phenolic hydroxyl groups cannot, as a rule, be replaced by means of the halogen hydrides.

Method II.—By the action of phosphorus halides or thionyl chloride on hydroxy-compounds.

The replacement of hydroxyl by halogen can be effected by the action of phosphorus halides on the hydroxy-compound. For the introduction of bromine or iodine it is not necessary actually to isolate the phosphorus halide, but merely to use

* *Morkownikoff*, A. 1866, 138, 364.

the elements in the necessary proportions. Usually red phosphorus is added to the hydroxy-compound and the theoretical amount of halogen introduced gradually.

1. **Preparation of Alkyl Halides.**

Experiment 33.—Ethyl iodide from ethyl alcohol:

$$PI_3 + 3C_2H_5OH = 3C_2H_5I + P(OH)_3.$$

2 g. of *yellow* phosphorus (weighed under water, cut into small pieces, and dried with filter paper) are added gradually to the theoretical amount of iodine contained in a 250 ml. round-bottomed flask. The flask is attached to a reflux condenser (fig. 80), and when cold 25 ml. (excess) of absolute alcohol are added gradually through the condenser tube. After the vigorous reaction has moderated, the flask is heated on a water bath with occasional shaking, until all the phosphorus iodide has been decomposed (1·5–2 hours). The ethyl iodide is then distilled off in the usual manner, either by immersing the flask in the boiling-water bath, or by heating on a sand bath. The distillate is freed from alcohol by washing several times with water. Should it be coloured brown by iodine it is again shaken with water to which a few drops of sodium hydroxide solution have been added. It is then dried over granular calcium chloride, decanted into a distilling flask and redistilled. Yield about 28 g., i.e. 95 per cent of theory, calculated from the amount of iodine taken.

It is a colourless liquid, b.p. 72°; $D^{0°}$, 1·944, and is slightly soluble in water but miscible in all proportions with alcohol and ether.

The replacement of hydroxyl by means of phosphorus halides is one of the most general reactions met with. By its means all the hydroxy-groups of aliphatic poly-hydric alcohols, the hydroxy-groups of phenols, and the hydroxy-groups of all types of acids can be replaced by halogen, e.g.:

$$\underset{\text{Glycerol}}{C_3H_5(OH)_3} + 3PCl_5 \rightarrow \underset{\text{Trichlorhydrin}}{C_3H_5Cl_3} + 3POCl_3 + 3HCl$$

$$\underset{\text{Phenol}}{C_6H_5{\cdot}OH} + PCl_5 \rightarrow \underset{\text{Chlorobenzene}}{C_6H_5Cl} + POCl_3 + HCl$$

$$\underset{\text{Acetic acid}}{3CH_3{\cdot}CO{\cdot}OH} + 2PCl_3 \rightarrow \underset{\text{Acetyl chloride}}{3CH_3{\cdot}COCl} + P_2O_3 + 3HCl$$

$$\underset{\text{Benzene-sulphonic acid}}{C_6H_5{\cdot}SO_2{\cdot}OH} + PCl_5 \rightarrow \underset{\text{Benzene-sulphonic chloride}}{C_6H_5{\cdot}SO_2Cl} + POCl_3 + HCl$$

In the case of phenols, however, the yields are unsatisfactory, owing to the phosphorus oxychloride, formed as a by-product, reacting with the residual phenol and giving rise to esters of phosphoric acid, e.g.:

$$POCl_3 + 3C_6H_5OH \rightarrow 3HCl + PO(OC_6H_5)_3.$$

Thionyl chloride, $SOCl_2$, is often used in place of phosphorus chlorides, especially for the preparation of acyl chlorides, with the exception of those derived from acids of high melting-point, and has the advantage that the other products of the reaction are gaseous:

$$R{\cdot}CO{\cdot}OH + SOCl_2 \rightarrow R{\cdot}COCl + SO_2 + HCl.$$

2. **Preparation of Acyl Halides.** (S.B. Chap. VII, B.)

Experiment 34.—Acetyl chloride from acetic acid. See equation above. *To be conducted in a fume chamber.*

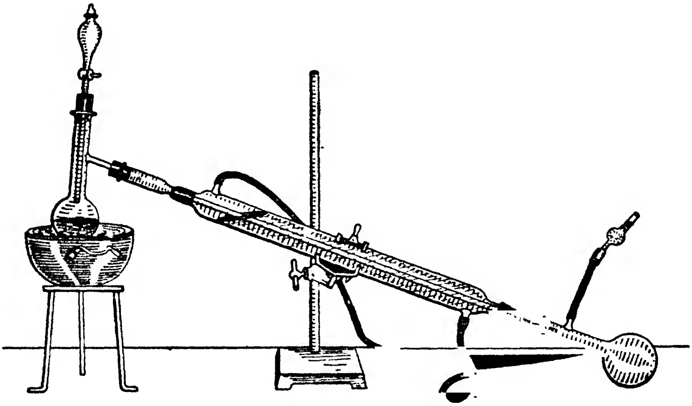


Fig. 79

60 g. of glacial acetic acid (m.p. 17°) are placed in a distilling flask of 200 ml. capacity, connected by the side tube to a condenser, and 46 g. of phosphorus trichloride added gradually from a dropping funnel. During the addition the flask is cooled by immersion in a water bath containing cold water. The temperature of the bath is then raised to 40–50°, and maintained at this until the evolution of hydrogen chloride slackens and the contents of the flask separate into two layers.

The water bath is then heated to boiling and the distillate collected in a second distillation flask communicating with the air through a calcium chloride tube attached to the side tube of the flask (fig. 79). The acetyl chloride is redistilled from the latter flask fitted with a thermometer, the same precautions being observed in collecting the distillate, and the portion passing over between 53° and 56° is collected separately. Yield, 50 g., i.e. 65 per cent of theory.

A colourless liquid which fumes strongly in air. B.p. 55°; $D^{0°}$, 1·13.

Experiment 35.—Benzoyl chloride from benzoic acid. *To be conducted in a fume chamber.*

10 g. of benzoic acid and four times the theoretical amount of thionyl chloride (freshly distilled) are placed in a 100 ml. flask fitted with a reflux condenser and the mixture warmed gently on the water bath. Hydrogen chloride and sulphur dioxide are evolved, and when the reaction subsides the mixture is cooled, transferred to a distilling flask, the excess of thionyl chloride distilled over and then the benzoyl chloride at a higher temperature.

A colourless liquid which fumes in air. B.p. 198°; $D^{19°}$, 1·214.

Experiment 36.—Benzene-sulphonic chloride from sodium benzene sulphonate,

$$C_6H_5{\cdot}SO_2{\cdot}ONa + PCl_5 \rightarrow C_6H_5{\cdot}SO_2Cl + POCl_3 + NaCl.$$

About 20 g. of phosphorus pentachloride are weighed out into a tared flask. The theoretical amount of sodium benzene-sulphonate (Exp. 125) is added gradually, and after the reaction is completed the contents of the flask are cooled and poured into an excess of cold water. The acyl halide, which is fairly stable towards water, is not affected, while the other products of the reaction go into solution. The oil is separated by means of a tap funnel, and is purified by distillation under diminished pressure. Yield, 15 g., i.e. 85 per cent of theory.

On a large scale it is economical to use the phosphorus oxychloride (cf. equation) to convert a further amount of the sodium sulphonate into acid chloride so that 1 mol of the pentachloride can react with 3 of the sulphonate. The method, however, is a lengthy one and requires intermittent shaking.

The chloride is a colourless oil which solidifies at low temperatures to crystals. M.p. 14·5°; b.p. 120° under 10 mm. pressure.

B. Replacement of Hydrogen by Halogen—Chlorination—Bromination—Iodination

(S.B. Chaps. II and XIX)

Halogen derivatives may readily be obtained by the direct replacement of hydrogen by the action of halogens on hydrocarbon groups. The reaction is of the type,

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl,$$

a molecule of halogen hydride being formed for each atom of hydrogen replaced. The action is generally accelerated by (*a*) sunlight, (*b*) heat, (*c*) the presence of " halogen carriers "—iodine, iron powder, sulphur, phosphorus, antimony pentachloride, aluminium chloride or bromide, the aluminium-mercury couple, are the substances chiefly used.

This substitution reaction is not well adapted for the preparation of halogen derivatives of the paraffin hydrocarbons, because mixtures of compounds are almost invariably produced and these are often difficult to separate. The method is more often applied in the case of the closed-ring hydrocarbons. Here the products formed depend entirely on the conditions of the reaction.

Experiment 37.—Bromobenzene, C_6H_5Br, from benzene.*

$$C_6H_6 + Br_2 \rightarrow C_6H_5Br + HBr.$$

50 g. of pure, dry benzene and about 0·5 g. of an aluminium-mercury couple are placed in a small flask. The couple is prepared by allowing small rolls of aluminum foil to stand in a strong solution of mercuric chloride for about a minute, then removing quickly and washing with water, alcohol, and finally with benzene. The flask is fitted to a reflux condenser provided with a dropping funnel and tube for leading off the hydrogen bromide (fig. 80) and 60 g. of *dry* bromine † dropped in. The addition should extend over half an hour. The mixture becomes quite warm and copious evolution of hydrogen bromide takes place, the gas being absorbed by the water in the beaker.

* *Cohen* and *Dakin*, J. C. S. 1899, 75, 894.

† Bromine is dried by shaking up with an equal volume of concentrated sulphuric acid in a tap funnel, allowing to stand for some time, and then running off the lower layer of bromine.

It is more convenient to measure out the bromine in a graduated cylinder or burette. D = 3.

When the mixture has cooled it is shaken with excess of dilute sodium hydroxide solution, separated, dried with granular calcium chloride and, when clear, decanted into a distilling flask and distilled. The portion boiling between

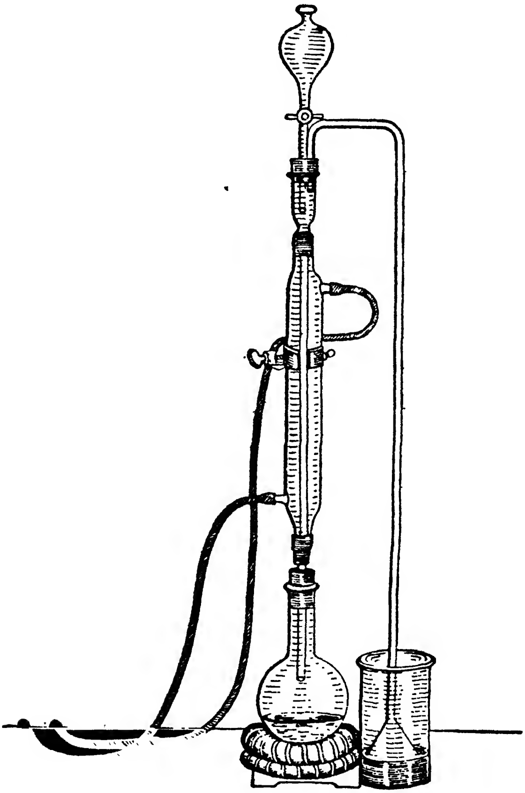


Fig. 80

140° and 170° is redistilled, and the fraction boiling at 150–160° collected. Yield, 30–35 g., i.e. 60 per cent of theory calculated on amount of bromine taken.

When pure it is a colourless liquid, b.p. 154–155°; $D^{12°}$, 1·502.

When the aromatic hydrocarbon contains a side chain, the product of the action of halogens depends on the conditions

under which the experiment is conducted. When the reaction takes place at ordinary temperatures in the presence of halogen carriers the halogen substitutes in the ring. In bright sunlight and at the boiling-point of the hydrocarbon the halogen enters the side chain.

Experiment 38.—Benzyl chloride, $C_6H_5{\cdot}CH_2Cl$, from toluene.

$$C_6H_5{\cdot}CH_3 + Cl_2 \rightarrow C_6H_5{\cdot}CH_2Cl + HCl.$$

50 g. of toluene (from Exp. 2) are introduced into a tared retort, the neck of which is tilted upwards and fitted to a reflux condenser. The retort is heated on a sand bath and the contents kept boiling gently while chlorine gas (prepared by the action of strong hydrochloric acid on *granular* manganese dioxide, and dried by bubbling through a wash bottle containing concentrated sulphuric acid or from a chlorine cylinder) is led in by a tube fitted through the tubulus of the retort. The liquid gradually turns yellow, and hydrogen chloride is evolved. The passage of the chlorine is continued until the contents of the retort (which is periodically weighed) have increased by the theoretical amount (18–19 g.). The liquid is then transferred to a distilling flask and fractionated, the portion boiling between 165° and 185° being collected separately. This portion is redistilled and the fraction boiling between 176° and 180° is nearly pure benzyl chloride. Yield, 40 g., i.e. 60 per cent of theory.

It is a colourless liquid, b.p. 176°; $D^{14°}$, 1·107; the vapour is very irritating to the mucous membranes of the nose and eyes.

Experiment 39.—Benzal chloride, $C_6H_5{\cdot}CHCl_2$, from toluene.

$$C_6H_5{\cdot}CH_3 + 2Cl_2 \rightarrow C_6H_5{\cdot}CHCl_2 + 2HCl.$$

The experiment is conducted in a similar manner to the last, the chlorine being led in until the theoretical increase of weight is attained (37 g.). The product is fractionated; some unchanged toluene and benzyl chloride pass over first, and the portion boiling at 205–213° is collected separately (use an air condenser). The product is purified by redistillation. It is a colourless liquid, b.p. 213°; $D^{16°}_{4°}$, 1·295.

Experiment 40.—*p*-Nitrobenzyl bromide from *p*-nitrotoluene.

$$NO_2{\cdot}C_6H_4{\cdot}CH_3 \rightarrow NO_2{\cdot}C_6H_4{\cdot}CH_2Br.$$

A solution of 10 g. *p*-nitrotoluene in 100 ml. of carbon tetrachloride containing a crystal of iodine is placed in a quartz

flask provided with a reflux condenser and illuminated by a mercury vapour lamp. 30 ml. of water are added, the mixture heated to gentle ebullition and 12·7 g. of bromine dissolved in 5 ml. of carbon tetrachloride dropped in slowly during a period of 20 min. The heating is continued until the solution is practically colourless. The carbon tetrachloride solution is separated, the solvent removed by distillation, and the *p*-nitrobenzyl bromide crystallized from alcohol. M.p. 97°–99°.

The bromide is largely used for the preparation of *p*-nitrobenzyl esters in the characterization of different acids. For this purpose, the potassium salt of the acid obtained by neutralizing an aqueous alcoholic solution of the acid with alcoholic potash (left just faintly acid) is mixed with an aqueous alcoholic solution of the bromide and the whole boiled for an hour. On cooling, the ester usually crystallizes. The amount of bromide to be used can be calculated from the amount of standard alkali required to neutralize the acid.

When the benzene ring already contains certain substituents, especially amino- or phenolic groups, the entrance of halogen into the ring takes place with great ease. Thus a solution of aniline in dilute hydrochloric acid yields a precipitate of the insoluble *s*-tribromaniline when treated with bromine water.

$$C_6H_5{\cdot}NH_2 + 3Br_2 \rightarrow C_6H_2Br_3{\cdot}NH_2(1{:}2{:}4{:}6) + 3HBr.$$

Sulphanilic acid, $C_6H_4(NH_2){\cdot}SO_3H(1{:}4)$, when treated with bromine in a similar manner, yields dibromosulphanilic acid,

$$C_6H_4(NH_2)SO_3H + 2Br_2 \rightarrow C_6H_2(NH_2)(SO_3H)Br_2(1{:}4{:}2{:}6) + 2HBr,$$

and phenol yields *s*-tribromophenol (m.p. 95°). The bromine atoms always tend to take the *o*- and *p*-positions with respect to the amino- and hydroxyl radicals.

Experiment 41.—Tribromaniline, $C_6H_2(NH_2)B_3$ (1 : 2 : 4 : 6), **from aniline.***

10 g. of aniline (Exp. 150) are dissolved in sufficient dilute hydrochloric acid, and the solution is made up to 500 ml. with water. The solution is placed in a pump flask, the side tube of which is attached to a pump, and the mouth of the flask is closed by a cork carrying a leading tube connected with a small wash bottle containing the theoretical amount of bromine (3 molecules for 1 molecule of aniline). A rapid stream of air, saturated with bromine vapour, is drawn through

* *Loring Jackson* and *Moore*, Am. 1890, **12**, 166.

the apparatus until the liquid assumes a permanent yellow colour. The precipitate of tribromaniline is filtered off on a porcelain funnel, washed with water, and dried on a porous plate. Yield almost theoretical. It crystallizes from hot alcohol in stout colourless needles, m.p. 119°.

Experiment 42.—2:4-Dichloro-α-naphthol, $C_{10}H_5(OH)Cl_2$ (1:2:4).

10 g. α-naphthol are dissolved in 100 ml. of glacial acetic acid which is then saturated with dry hydrogen chloride and the whole weighed. Dry chlorine gas is then led into the solution until there is an increase in weight of 5 g. (theoretical for $2Cl_2$—2HCl is 4·8 g.). The product is poured into excess of water, the precipitate filtered off and crystallized from an alcohol-water mixture. It consists of long colourless needles, m.p. 107°. Yield, 75 per cent.

Experiment 43.—Dibromosulphanilic acid, $C_6H_2Br_2(NH_2)(SO_3H)$ (1:4:2:6), **from sulphanilic acid.**

20 g. of sulphanilic acid (Exp. 127) are dissolved in the smallest possible quantity of dilute sodium hydroxide solution, and then diluted with water to about 2 litres and a slight excess of dilute hydrochloric acid added; usually no precipitate of sulphanilic acid appears. The mixture is placed in a Winchester quart bottle attached to a pump and to a small wash bottle containing the theoretical amount of bromine, and a rapid stream of air saturated with bromine vapour drawn through the solution. When all the bromine has disappeared the liquid is filtered, if necessary, and evaporated. On cooling, colourless crystalline needles of dibromosulphanilic acid separate. Yield, 90 per cent.

Halogen substitution products of the aliphatic carboxylic acids may also be prepared by the direct action of the halogen on the acids, e.g.—

$$\underset{\text{Acetic acid}}{CH_3{\cdot}COOH} + Cl_2 \rightarrow \underset{\text{Monochloracetic acid}}{CH_2Cl{\cdot}COOH} + HCl.$$

By continued action of the halogen di- and tri-substituted acids are obtained.

The Hell-Volhard-Zelinsky Reaction.—The direct halogenation of acids takes place with difficulty, but the action proceeds readily if the acyl halides or acyl anhydrides (Chap. XIV, A) are treated with the halogen. The action on the acid is greatly facilitated by sunlight, and especially by the addition of red

phosphorus. In the latter case the reaction proceeds in two stages:

(*a*) The production of the acyl halide by the action of the phosphorus halide on the acid. (Cf. Exps. 34 and 35.)

(*b*) The halogenation of the acyl halide.

The complete reaction may be represented by the following equation:

$$3X{\cdot}CH_2COOH + P + 8Br \rightarrow 3X{\cdot}CH_2Br{\cdot}COBr + HPO_3 + 2HBr.$$

The halogen acid may be obtained from the acyl compound by treatment with water. (Cf. properties of acyl halides, p. 142.)

The reaction is of great importance for the preparation of halogen derivatives of acids, and is also of theoretical interest, for the halogen always enters the molecule in the α-position to the carboxylic group, e.g.

$CH_3{\cdot}CH_2{\cdot}CO_2H$	$\rightarrow$	$CH_3{\cdot}CHBr{\cdot}COBr$ *
Propionic acid		α-Bromo-propionyl bromide
$COOH{\cdot}CH_2{\cdot}CH_2{\cdot}COOH$	$\rightarrow$	$COBr{\cdot}CH_2{\cdot}CHBr{\cdot}COBr$ †
Succinic acid		α-Bromo-succinyl bromide

Acids, which have no hydrogen atom in the α-position, e.g. trimethyl-acetic acid, $(CH_3)_3C{\cdot}COOH$, cannot be brominated by this method.

Experiment 44.—Monobromacetic acid, $CH_2Br{\cdot}CO_2H$, from acetic acid.

$$3CH_3{\cdot}CO_2H + P + 8Br = 3CH_2Br{\cdot}COBr + HPO_3 + 2HBr.$$

For success in this preparation the materials used must be thoroughly purified and dried. The acetic acid is purified by distillation and freezing, and the bromine is dried by shaking with concentrated sulphuric acid (see note, Exp. 37). The red phosphorus should be warmed with dilute ammonia solution, then washed well with water and dried in a steam oven.

A mixture of 20 g. of pure acetic acid and 3 g. of red phosphorus is placed in a round-bottomed flask of about 300 ml. capacity, fitted up as shown in fig. 80. (Note.—*Rubber stoppers should not be used.*) The bromine is added from the dropping funnel, very gradually at first, the flask being cooled by im-

* *Zelinsky*, B. 1887, **20**, 2026. † *Volhard*, A. 1887, **242**, 141.

mersion in cold water. The reaction proceeds with great vigour, but moderates after about half the bromine has been added, when the remainder may be run in more quickly. The flask is then warmed on a boiling-water bath until the colour of bromine vapour in the interior of the flask disappears. After cooling, the bromacetyl bromide is poured into a distilling flask and distilled under diminished pressure (fig. 9). The product is weighed and the theoretical amount of water required to convert it into bromacetic acid added gradually. The mixture solidifies to a white crystalline mass. This is purified by distilling under ordinary pressure from a small distilling flask provided with an air condenser (fig. 82), the portion distilling between 190° and 210° being collected.

It forms colourless crystals, m.p. 50–51°, b.p. 208°. The yield is variable.

Note.—The bromacetyl bromide and bromacetic acid must not be allowed to touch the hands, as they cause serious wounds.

Experiment 45.—α-Bromostearic acid, $CH_3 \cdot (CH_2)_{15} \cdot CHBr \cdot CO_2H$, **from stearic acid.**

30 g. of stearic acid and the requisite amount of red phosphorus are placed in a flask fitted with a reflux condenser and dropping funnel (fig. 81). The flask is immersed in a water bath containing water at 60–70° so that the stearic acid melts, and the theoretical amount of dry bromine is added gradually from a dropping funnel; when addition is complete, the mixture is heated on a boiling-water bath for about three hours. The product is poured into water and the monobromostearic acid filtered off and dried on a porous plate.

It crystallizes from carbon disulphide in colourless plates. M.p. 61°.

Halogenation in the presence of oxidizing agents.—In all the methods already described 50 per cent of the halogen used is not directly utilized in the formation of the halogenated carbon compound but is eliminated as halogen hydracid. Methods based on the use of bromine or iodine in the presence of an oxidizing agent, e.g. nitric acid,* sodium persulphate,† or iodic acid, have been introduced, and by such methods the whole of the halogen is available for halogenation, as the oxidizing agent converts the hydrogen halide into halogen.

* *Datta* and *Chatterjee*, J. A. C. S. 1916, 2545; 1917, 435; 1919, 292.

† *Elbs* and *Jaroslavzev*, J. pr., 1913, [ii], 88, 92.

Experiment 46.—Iodobenzene, C_6H_5I, from benzene.

20 g. benzene, 20 g. iodine, and 80 g. sodium persulphate with 60 ml. glacial acetic acid are heated in a reflux apparatus for 15 hours. The product is diluted with water, the oily iodobenzene separated, washed, dried and distilled. Yield, 70 per cent; b.p. 185°.

For halogenation of amides, cf. Chap. XXXIII, A.

C. Replacement of Amino-groups by Halogens

This reaction is carried out by the agency of the diazo-reaction (Chap. XX, D).

D. Replacement of Sulphonic Groups by Halogens

The sulphonic group in certain amino-sulphonic acids is readily replaced by chlorine, bromine or iodine when the sulphonic group is in the *o*- or *p*-position with respect to the amino-group. Thus theoretical yields of *s*-tribromaniline are formed by adding bromine water to an aqueous solution of potassium 2:6-dibromosulphanilate (Exp. 43) or the isomeric 4:6-dibromo-2-sulphonate. In the anthraquinone series replacement of a sulphonic group occurs when this group is in the α-position in the quinone.

Experiment 47.—1-Chloranthraquinone from anthraquinone-1-sulphonic acid.*

40 g. of the potassium salt (p. 193), 170 ml. of concentrated hydrochloric acid, and 1200 ml. of water are placed in a three-litre flask fitted with a reflux condenser and a fast-moving stirrer. The contents are heated to boiling, and to the boiling mixture a solution of 40 g. of sodium chlorate in 200 ml. of water is added by drops over a period of three hours. Chloranthraquinone separates immediately and by proper control of the operation no unused chlorine is developed. At the end of the reaction the mass is boiled for one hour and the chloranthraquinone filtered, washed with warm water, and dried. Yield, 28 g.; 95 per cent theoretical.

It crystallizes from alcohol as yellow needles, m.p. 162°.

* *Ullmann* and *Ochsner*, A. *1911*, *381*, 2.

E. Addition of Halogens or Hydrogen Halides to Unsaturated Compounds

(S.B. Chap. II)

Examples of this type of reaction are afforded by the following equations:

$$\underset{\text{Ethylene}}{CH_2{:}CH_2} + HBr \rightarrow \underset{\text{Ethyl bromide}}{CH_3{\cdot}CH_2Br}$$

$$\underset{\text{Propylene}}{CH_3{\cdot}CH{:}CH_2} + Br_2 \rightarrow \underset{\text{Propylene dibromide, 1:2-dibromo-propane}}{CH_3{\cdot}CHBr{\cdot}CH_2Br}$$

$$\underset{\text{Acetylene}}{CH{\vdots}CH} + 2Br_2 \rightarrow \underset{\text{Acetylene tetrabromide}}{CHBr_2{\cdot}CHBr_2} \text{ (cf. Exp. 20 (3)).}$$

Experiment 48.—Ethylene dibromide from ethylene.

$$CH_2{:}CH_2 + Br_2 \rightarrow CH_2Br{\cdot}CH_2Br.$$

Ethylene is prepared and purified as described in Exp. 16. The gas is bubbled slowly through two wash bottles with ground-glass stoppers (fig. 76), each containing 20 g. of bromine and 20 ml. of water, until the colour of the bromine completely disappears. Should the contents of the flask in which the ethylene is being generated char badly (a slight amount of charring is inevitable), the operation is stopped and a fresh supply of gas made.

When decolorization is complete the contents of the wash bottles are removed to a separating funnel, the oily layer removed, and shaken with dilute sodium carbonate solution until colourless. The lower layer of ethylene dibromide is removed, dried over granular calcium chloride, and distilled. Yield, 40–45 g.

It is a colourless oil. B.p. 131°; D, 2·189.

The method of preparation can be made less tedious either by preparing the gas, with orthophosphoric acid in the place of sulphuric acid, or by collecting the ethylene in a large gas holder, measuring its volume, and bubbling it very slowly through rather less than the theoretical amount of bromine.

In the preparation of a dihalogen derivative by this method the two halogen atoms become attached to two adjacent carbon atoms, except when two conjugate double bonds are present (e.g. cinnamylidene-acetic acid, $C_6H_5{\cdot}CH{:}CH{\cdot}CH{:}CH{\cdot}CO_2H$, Exp. 287), when the bromine frequently enters into the 1:4 positions.

$$C_6H_5{\cdot}CH{:}CH{\cdot}CH{:}CH{\cdot}COOH + Br_2 \rightarrow C_6H_5CHBr{\cdot}CH{:}CH{\cdot}CHBr{\cdot}COOH.$$

Experiment 49.—Dipentene bishydrochloride, $C_{10}H_{16}2HCl$.

Dry hydrogen chloride is passed into a mixture of dipentene (2 vols.) and acetic acid (1 vol.) which is shaken at intervals. The crystalline product is removed, washed with water, drained and crystallized from aqueous alcohol. M.p. 51°.

Experiment 50.—Bornyl chloride (artificial camphor) from α-pinene.

α-Pinene (obtained by fractional distillation of American oil of turpentine), b.p. 156°, diluted with an equal volume of dry carbon tetrachloride, is placed in a wash bottle cooled by running water or ice, and dry hydrogen chloride passed through the mixture. Colourless crystals ($C_{10}H_{17}Cl$) separate, which are removed and washed with dry carbon tetrachloride. M.p. 132°. They possess an odour similar to that of camphor, but are quite different in composition. This addition involves a *Wagner-Meerwein change*.

Olefines form additive compounds not only with halogens and halogen hydracids but also with compounds like (i) bromine chloride or iodine chloride (ICl), (ii) halogen hydroxy acids, HClO and HBrO, and (iii) nitrosyl chloride, NOCl. In the first examples two different halogen atoms add on at the olefine link, in the second OH and halogen, and in the third NO and chlorine.

Experiment 51.—Pinene nitrosochloride, $(C_{10}H_{16}NOCl)_2$.

α-Pinene (7 ml.), amyl nitrite (10 ml.), and glacial acetic acid (15 ml.) are mixed and cooled in a freezing mixture. A well-cooled mixture of 5·5 ml. of concentrated hydrochloric acid with an equal volume of glacial acetic acid is then added gradually with continuous stirring. The blue colour which develops should disappear before each further addition of the acid. The additive compound separates as a white crystalline powder and is recrystallized from benzene. Yield, 5 g.; m.p. 103°.

Molecular weight determinations indicate that the compound is dimeric. On treatment with alkali it regenerates α-pinene, and its formation can consequently be applied to the isolation of α-pinene from mixtures.

F. Special Methods

Chloroform results from a process of simultaneous oxidation and chlorination of alcohol or acetone by means of bleaching-

powder solution. Iodoform is obtained in a similar manner by using an alkaline solution of iodine.

Experiment 52.—Chloroform, $CHCl_3$, from ethyl alcohol.*

$$4C_2H_5OH + 16CaOCl_2 \rightarrow 13CaCl_2 + 3(H \cdot CO_2)_2Ca + 8H_2O + 2CHCl_3.$$

100 g. of bleaching powder are rubbed into a paste with about 300 ml. of water and placed in a large flask of 2 litres capacity fitted to a condenser and receiver. 20 g. of rectified spirit (or of acetone) are added, and the mixture gradually heated on a sand bath. The reaction is accompanied by much frothing, and the distillation is continued as long as oily drops of chloroform pass over. The product is separated from the aqueous layer, shaken with dilute sodium hydroxide solution, dried over granular calcium chloride, and purified by redistillation. Yield, 20 g.

It is a colourless liquid with a sweetish odour. B.p. 61–62°; $D^{0°}$, 1·526.

Experiment 53.—Iodoform, CHI_3, from ethyl alcohol.

5 g. of alcohol are added to a solution of 10 g. of potassium carbonate in 40 ml. of water, and to the mixture 10 g. of iodine are added in small portions with stirring. The whole is heated gradually to a temperature of 80° and then allowed to cool. Iodoform separates in the form of small yellow crystals, which are filtered and washed with water.

It has a characteristic odour. It melts at 120°, dissolves readily in alcohol and ether and is volatile with steam.

Acetone or lactic acid may be substituted for alcohol in this preparation.

Experiment 54.—Methyl iodide from methyl sulphate.†

$$KI + (CH_3)_2SO_4 \rightarrow CH_3I + CH_3KSO_4.$$

A solution of 50 g. of potassium iodide in its own weight of water is warmed in a distillation flask fitted to a condenser, and 40 g. of methyl sulphate ‡ are run in slowly from a dropping funnel. The methyl iodide distils over and can be purified as in Exp. 30. As methyl iodide is very volatile, a rapid stream of cold water should be kept circulating through the condenser, and the receiver may be partly filled with ice and water. Yield, 39 g.

* *Liebig*, A. 1832, **1**, 199. † *Weinland* and *Schmid*, B. 1905, **38**, 2327.

‡ *N.B.*—Methyl sulphate is exceedingly poisonous, and all operations with it should be conducted in a good fume cupboard.

It is a colourless liquid, b.p. 45°, and closely resembles ethyl iodide.

G. Replacement of Chlorine or Bromine by Iodine

Experiment 55.—Iodo-acetic acid, $CH_2I{\cdot}COOH$, **from chlor-acetic acid.**

$$CH_2Cl{\cdot}COOH + KI \rightarrow CH_2I{\cdot}COOH + KCl.$$

20 g. of chlor-acetic acid are heated in a flask fitted with a reflux condenser on a water bath for an hour with 100 ml. of absolute alcohol and 40 g. of powdered potassium iodide. After cooling, the product is filtered from the precipitate of potassium chloride and remaining iodide, and the filtrate evaporated to a small bulk on a water bath. On cooling, crystals of iodo-acetic acid separate. These are purified from potassium iodide by dissolving in ether, filtering, and evaporating the filtrate.

Iodo-acetic acid consists of white crystalline plates, m.p. 84°. The vapours are irritating to the eyes, and the solid causes serious burns if handled. The later stages of the experiment should therefore be carried out in a well-ventilated fume chamber.

H. Replacement of Hydrogen by the Chlormethyl Group. Chlormethylation

It is possible to replace a hydrogen atom in many types of compounds by the chlormethyl group ($\cdot CH_2Cl$) in a single operation.* Thus benzene may be converted into benzyl chloride by reaction with formaldehyde and hydrogen chloride with anhydrous zinc chloride as condensing agent.

$$C_6H_6 + CH_2O + HCl \rightarrow C_6H_5{\cdot}CH_2Cl + H_2O.$$

Paraformaldehyde, 40 per cent formalin, or methylal may be used as sources of formaldehyde.

Experiment 56.—Benzyl chloride from benzene.

A mixture of 200 g. benzene, 40 g. 40 per cent formalin, and 50 g. pulverized anhydrous zinc chloride is heated in a flask kept in a water bath at 60°. The flask is shaken frequently while a stream of hydrogen chloride is passed through the mixture until no more is absorbed (15 to 20 min.). The aqueous layer is removed and the benzene layer washed in a separating

* *Grassi* and *Maselli*, Gazz. 1898, **28**, II, 477.

funnel, first with water and then with dilute sodium bicarbonate solution, then dried over calcium chloride and distilled. After removal of excess benzene, benzyl chloride passes over and is collected at 176–180°.

The reaction is applicable to many types of organic compounds and is useful inasmuch as the $\cdot CH_2Cl$ group can be converted into other groups such as $\cdot CH_2\cdot OH$, $\cdot CHO$, $\cdot CH_2CN$, &c.

Chlorethylation ($\cdot CHCl\cdot CH_3$) may also be carried out by the use of paraldehyde in place of formaldehyde.

J. Chemical Reactions of the Halogen Derivatives

Organic compounds containing halogens, considered from the point of view of the halogen only, may be divided into three groups:

(i) Compounds derived from open-chain hydrocarbons by the substitution of halogen for hydrogen, e.g. ethyl iodide, C_2H_5I. The group includes closed-ring compounds containing halogen in the side chain, e.g. benzyl chloride, $C_6H_5CH_2Cl$. Substances containing several halogen atoms in the molecule, e.g. chloroform, $CHCl_3$, and compounds containing other organic radicals, e.g. bromacetic acid, $CH_2Br\cdot COOH$, may be included in this class.

(ii) Compounds derived from closed-chain hydrocarbons and their derivatives by substitution of halogen for hydrogen in the ring, e.g. bromobenzene, C_6H_5Br; chlorotoluene, $C_6H_4Cl\cdot CH_3$.

(iii) Acyl halides—compounds produced by the replacement of the hydroxy-group of acids by halogen, e.g. acetyl chloride, $CH_3\cdot COCl$; benzene-sulphonic chloride, $C_6H_5\cdot SO_2Cl$.

Mixed compounds may be obtained, e.g. bromacetyl bromide, $CH_2Br\cdot COBr$.

Group I.—The simple halogen compounds of this group are generally heavy liquids which are only sparingly soluble in water but readily soluble in alcohol and ether. They give no precipitates of silver halides when shaken with silver nitrate solution. (Exceptions: methyl iodide, which gives a copious precipitate, and ethyl iodide, which gives a slight precipitate.) They are practically unaffected by cold water, but are gradually hydrolysed when boiled with water:

$$C_2H_5Br + H_2O \rightleftharpoons C_2H_5OH + HBr.$$

When treated with cold dilute alkalis—shaking with cold dilute potassium hydroxide solution—they are partially hydrolysed, but the amount of oil is not appreciably diminished:

$$C_2H_5Br + KOH \rightarrow C_2H_5OH + KBr.$$

If the aqueous liquid, after such treatment with alkali, is acidified with nitric acid and silver nitrate added, a precipitate of silver halide is obtained.*

Warming with excess of alkali causes complete hydrolysis.

Group II.—The simple compounds of this class are either colourless liquids or crystalline solids, insoluble in water, but soluble in alcohol and ether. They are extremely stable, and the halogen cannot be removed from the molecule at all readily. Thus they are not affected by alkalis (test the aqueous liquid as above, after addition of nitric acid, with silver nitrate solution). The halogen can be replaced by treatment with absolute alcohol and metallic sodium.

Group III.—The acyl halides are generally fuming liquids (yielding fumes of hydrogen halide in contact with moist air) or crystalline solids. They are extremely reactive, the aliphatic members of the class reacting vigorously with water, e.g.:

$$CH_2Br{\cdot}COBr + H_2O = CH_2Br{\cdot}CO_2H + HBr.$$

The aromatic members (e.g. benzoyl chloride, $C_6H_5{\cdot}COCl$) are only attacked slowly by cold water, while the sulphonic derivatives (e.g. benzene-sulphonic chloride, $C_6H_5SO_2Cl$) are comparatively stable. All the acyl halides are completely hydrolysed by treatment with boiling water or by shaking with dilute alkalis. The oil disappears under this treatment, and the resulting solution, acidified with nitric acid, gives a copious precipitate of silver halide with silver nitrate solution:

$$C_6H_5COCl + 2KOH = C_6H_5COOK + KCl + H_2O.$$

The acyl halides react readily with ammonia, yielding acyl amides (Chap. XIV, B):

$$C_6H_5COCl + 2NH_3 = \underset{\text{Benzamide}}{C_6H_5CONH_2} + NH_4Cl.$$

These are generally crystalline solids of definite melting-point, and can therefore be used for the characterization of the acyl halides from which they are prepared.

* The alkali used must be free from halides.

The acyl halides react readily with primary amines, yielding substituted amides (Chap. XIX, A), and when treated with alcohols or other hydroxy-compounds, fragrant smelling esters are obtained (Chap. XIII, D).

XII. CARBOXYLIC ACIDS

Characteristic of these acids is the presence of the carboxylic group $-C\begin{matrix}\diagup\!\!\!\diagup O\\ \diagdown H\end{matrix}$, and their reactivity is largely due to the readiness with which the hydrogen radical of the carboxylic group can be replaced. The basicity of any given acid depends upon the number of such carboxylic groups present in the molecule.

A. Oxidation of Hydrocarbons
(S.B. Chap. XXVI)

Method I.—As a rule, a saturated aliphatic hydrocarbon cannot be oxidized directly; on the other hand, olefine and acetylene hydrocarbons are readily oxidized, the molecule in each case being ruptured if a moderately strong oxidizing agent is used, and a mixture of acids or ketones containing a smaller number of carbon atoms is obtained. The rupture always occurs between the two carbon atoms originally united by the double or triple bond, and thus the method is used in order to determine the exact position of the double or triple bond in the molecules of unsaturated hydrocarbons and their derivatives. The method is, however, not generally used for the preparation of acids.

The oxidation of homologues of benzene is a method frequently adopted for the preparation of aromatic acids, the reaction consisting in oxidizing one or more side chains into carboxylic groups by means of common oxidizing materials. In many cases the oxidation is facilitated by the introduction of a halogen atom into the side chain.

Experiment 57.—Benzoic acid, $C_6H_5{\cdot}COOH$, **from benzyl chloride,** $C_6H_5{\cdot}CH_2Cl$.

Benzyl chloride may be oxidized by means of an alkaline solution of potassium permanganate. The reactions are represented by the equations

$$C_6H_5{\cdot}CH_2Cl \rightarrow C_6H_5{\cdot}CH_2{\cdot}OH$$

$$3C_6H_5{\cdot}CH_2{\cdot}OH + 4KMnO_4$$
$$= 3C_6H_5{\cdot}COOK + 4MnO_2 + KOH + 4H_2O.$$

A mixture of 5 g. of benzyl chloride (Exp. 38), with a solution of 4 g. of anhydrous carbonate sodium in 50 ml. of water, is boiled gently in a reflux apparatus, the theoretical amount of potassium permanganate required by the equation dissolved in 150 ml. of water is added gradually, and the mixture boiled until the purple colour of the permanganate has disappeared, and has been replaced by the brown precipitate of hydrated manganese peroxide. A stream of sulphur dioxide is then led into the hot liquid, until the precipitate of manganese peroxide is completely dissolved. On cooling, crystals of benzoic acid separate. These are removed by filtration, using a porcelain funnel, washed with a little water, and recrystallized from hot water. Yield about 4·5 g. —almost theoretical.

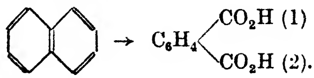
The acid forms colourless needles, m.p. 121°. It sublimes at a higher temperature, is very sparingly soluble in cold water, but fairly soluble in hot water, alcohol, and ether, and is volatile with steam.

The acid is soluble in caustic alkalis, yielding soluble salts, from which the free acid is reprecipitated on the addition of mineral acids. Its silver, calcium, lead, and ferric salts are insoluble, or very sparingly soluble, in water. When heated with soda-lime the acid yields benzene:

$$C_6H_5CO_2H + 2NaOH = C_6H_6 + Na_2CO_3 + H_2O.$$

Experiment 58.—Phthalic acid, $C_6H_4(CO_2H)_2$, from naphthalene,* $C_{10}H_8$.

To be conducted in a fume chamber.



The process is one of oxidation by means of concentrated sulphuric acid, using mercuric sulphate or metallic mercury as a catalytic agent.

* D. R. P. 91, 202; L.-C., p. 613.

20 g. of naphthalene and 10 g. of mercuric sulphate are placed in a large retort (500 ml.), with a mixture of 260 g. of concentrated sulphuric acid and 40 ml. of water. A thermometer fixed by a cork through the tubulus of the retort dips into the liquid, and a flask is used as receiver. As the mixture is gently heated the naphthalene dissolves; oxidation begins at about 200°, and at 250° the evolution of carbon dioxide and sulphur dioxide is rapid. Phthalic acid and its anhydride distil over together with sulphuric acid, and are condensed in the receiver, which is cooled, if necessary, with water. The temperature is finally raised to 300°, and the heating continued until the contents of the retort become almost solid. The residue of mercuric sulphate can be used for a further operation. The distillate is diluted with twice its volume of water, and boiled for some time. After cooling, the solid is filtered by means of a porcelain funnel, washed with a little cold water, and dried. Yield, 8–10 g., i.e. 35–40 per cent of theory. It crystallizes from hot water in short prisms, melts at 213° when heated very quickly, and sublimes on further heating, yielding its anhydride (see Exp. 100). It is very sparingly soluble in water, but dissolves in alcohol and ether.

The acid dissolves in caustic alkalis, yielding soluble salts. The silver and barium salts are insoluble in water. When heated with soda-lime it yields benzene:

$$C_6H_4(CO_2H)_2 + 4NaOH = 2Na_2CO_3 + 2H_2O + C_6H_6.$$

In the manufacture of phthalic acid from naphthalene the oxidation is effected by atmospheric oxygen in the presence of a vanadium oxide catalyst.

B. Oxidation of Primary Alcohols, Aldehydes and Ketones

Method II.—Although the paraffins themselves are not readily oxidized, many of their oxygenated derivatives are readily converted into carboxylic acids by further oxidation. Every primary alcohol, whether of the aliphatic or aromatic series, when oxidized yields an aldehyde and then a monobasic acid, both containing the same number of carbon atoms as the original alcohol:

$$R{\cdot}CH_2{\cdot}OH \rightarrow R{\cdot}C\begin{matrix}\diagup H\\ \diagdown\!\!\diagdown O\end{matrix} \rightarrow R{\cdot}C\begin{matrix}\diagup OH\\ \diagdown\!\!\diagdown O\end{matrix}.$$

These reactions are of theoretical rather than practical value, but are utilized in the carbohydrate group for the preparation of certain acids, e.g. gluconic and saccharic acids.

Experiment 59.—*d*-Gluconic acid from *d*-glucose.*

A mixture of 10 g. bromine with a solution of 10 g. glucose in 50 ml. of water is kept for 1–2 days in a warm place with occasional shaking. The mixture is distilled under reduced pressure at 60° until the solution is colourless. The bromide content is determined by the *Volhard method* and the free hydrobromic acid accurately neutralized by the addition of the required amount of sodium carbonate. To the boiling solution calcium carbonate is added gradually until neutral. The precipitate is filtered and the clear filtrate kept in an ice chest for 2 to 3 days when calcium gluconate separates and can be obtained pure by crystallization from water.

Experiment 60.—Potassium hydrogen *d*-saccharate, $COOH\cdot(CH\cdot OH)_4\cdot COOK$, **from *d*-glucose.**

25 g. *d*-glucose are evaporated in a dish on a water bath with 150 ml. of dilute nitric acid (sp. gr. 1·15) until a thick syrup is left. Water (50 ml.) is added and the evaporation repeated. Water is again added (50 ml.) and a strong solution of potassium carbonate until a neutral solution is obtained. 12·5 ml. of a 50 per cent solution of acetic acid are then added, the solution evaporated to 40 ml. and allowed to stand until crystallization takes place. The product is filtered and recrystallized from a little water, animal charcoal being used to remove any colour.

Open-chain ketones on oxidation usually yield a mixture of acids containing a lesser number of carbon atoms due to fission of the molecule; on the other hand, cyclic ketones, e.g. camphor, yield dibasic acids containing the same number of carbon atoms.

Experiment 61.—Oxidation of camphor to camphoric acid,

$$C_8H_{14}\left\langle\begin{array}{l}CH_2\\ |\\ CO\end{array}\right. \rightarrow C_8H_{14}(CO_2H)_2.$$

30 g. of camphor are heated with 400 ml. of nitric acid of sp. gr. 1·27 (2 vols. of conc. acid to 1 of water) in a litre flask with a long, ground-in air condenser and placed in a boiling-water bath. The heating is continued until the camphor dis-

* *Kiliani*, A. 1880, **205**, 182.

appears and the vapour in the air condenser is only feebly coloured—approximately 50 hours. On cooling, crystals of camphoric acid separate with a little camphor. The solid is removed, washed with water, and treated with dilute caustic soda to separate the camphor and camphoric acid. The clear alkaline liquid when acidified yields the acid which can be crystallized from water. Yield, 50 per cent; m.p. 187°.

C. By the Elimination of Carbon Dioxide from a Dibasic Acid

Method III.—Many dibasic acids are perfectly stable, and show very little tendency to lose carbon dioxide, others, e.g. oxalic and malonic acids, evolve carbon dioxide readily when heated, yielding corresponding monobasic acids.

$$\boxed{COO}H\cdot COOH \text{ (oxalic)} \rightarrow H\cdot COOH \text{ (formic)}$$

$$\boxed{COO}H\cdot CH_2\cdot COOH \text{ (malonic)} \rightarrow CH_3\cdot COOH \text{ (acetic)}.$$

This reaction appears to be characteristic of dibasic acids in which the two carboxyl groups are directly united, as in oxalic acid, or in which they are both attached to the same carbon atom, as in malonic acid and its substituted derivatives (cf. Malonic ester synthesis, Chap. XXV).

Experiment 62.—Formic acid from oxalic acid.

A good yield of formic acid cannot be obtained by merely heating oxalic acid, as a certain portion of the oxalic acid sublimes unchanged. The oxalic acid is therefore heated with glycerol when carbon dioxide and glyceryl monoformate are obtained, and the latter when boiled with water yields formic acid and glycerol:

$$\begin{matrix} COOH \\ \cdot \\ COOH \end{matrix} + C_3H_5(OH)_3 = CO_2 + H_2O + C_3H_5(OH)_2\cdot O\cdot C\begin{matrix} \diagup H \\ \diagdown O \end{matrix}$$

$$C_3H_5(OH)_2\cdot O\cdot C\begin{matrix} \diagup H \\ \diagdown O \end{matrix} + H\cdot OH = C_3H_5(OH)_3 + H\cdot C\begin{matrix} \diagup O \\ \diagdown OH \end{matrix}$$

30 g. of glycerol are weighed in an evaporating dish and dehydrated by heating on a sand bath until a thermometer immersed in the liquid indicates a temperature of 175–180°. It is then introduced into a distilling flask of about 200 ml. capacity and 30 g. of crystallized oxalic acid ($H_2C_2O_4\cdot 2H_2O$)

added. The side tube of the flask is attached to a condenser, and a thermometer introduced through the neck of the flask dips *into* the liquid. The mixture is heated gradually on a sand bath, and the temperature maintained at about 110° until the evolution of carbon dioxide gas slackens. When this occurs the contents of the flask are allowed to cool somewhat and a fresh portion of 30 g. of oxalic acid added. The heating is renewed, the reaction recommences, and an aqueous solution of formic acid distils over into the receiver. The reaction is a continuous one, and an abundant supply of the distillate may be obtained by the addition of similar quantities of oxalic acid at intervals. The water of crystallization of the oxalic acid serves to hydrolyse the glyceryl monoformate. The residue in the flask after each distillation contains this ester (see Esters, Chap. XIII, D).

The product in this experiment is an aqueous solution of formic acid.

For the preparation of crystallized specimens of the lead and copper salts, cf. Chap. XII, Exps. 71, 73.

Experiment 63.—Anhydrous formic acid.

Place 20 g. of the dry lead salt in a vertical glass tube drawn out at the bottom, pass in a stream of dry hydrogen sulphide from the top. Collect the oil which flows away from the bottom, and distil from a small flask containing a few grams of lead formate.

The anhydrous acid is a colourless liquid with a penetrating odour, b.p. 100°. It is miscible in all proportions with water and alcohol.

The acid and its salts when heated with concentrated sulphuric acid yield pure carbon monoxide:

$$HCO{\cdot}OH \rightarrow H_2O + CO.$$

The salts, with the exception of the silver salt and sparingly soluble lead salt, are readily soluble in water. The ferric salt, obtained by adding ferric chloride to a neutral solution of a formate, forms a blood-red solution which deposits a reddish precipitate of basic ferric formate on warming (cf. Acetate). Silver formate readily decomposes, depositing metallic silver.

Experiment 64.—Silver mirror test.

Add silver nitrate to a neutral solution of a formate. A white precipitate is obtained which darkens on exposure to light. Dissolve the precipitate by adding a few drops of ammonia

solution, and warm the resulting solution in a chemically clean test tube in a water bath. A silver mirror is deposited.

Formates also show other reducing properties. With a solution of mercuric chloride, a white precipitate of mercurous chloride is obtained.

Distinction between Formates and Acetates.—These two classes of salts may be distinguished by their reaction in *neutral* solution with silver nitrate. Formates yield a white precipitate which is easily reduced to metallic silver, while acetates in dilute solution yield no precipitate. The former decompose when treated with concentrated sulphuric acid and alcohol, yielding carbon monoxide, while the latter yield the fragrant-smelling ester.

D. The Hydrolysis of an Ester of the Acid

Method IV.—The esters (Chap. XIII, D) of many acids occur naturally, and the acids may be obtained by the hydrolysis (saponification) of such esters either by means of dilute mineral acids or of alkalis,

$$CH_3{\cdot}COOC_2H_5 + KOH = CH_3{\cdot}COOK + C_2H_5OH,$$

the products formed being the acid, or its alkali salt, and the alcohol. Many of the natural fats and oils are esters of the trihydric alcohol glycerol, $C_3H_5(OH)_3$, with certain saturated and unsaturated monobasic acids, and when hydrolysed with alkalis, as in the manufacture of soap, yield the alkali salts of the acids and glycerol.

Experiment 65.—Oleic acid from olive oil.

$$C_3H_5(O{\cdot}CO{\cdot}C_{17}H_{33})_3 + 3NaOH \rightarrow C_3H_5(OH)_3 + 3C_{17}H_{33}CO_2Na.$$

30 g. of olive oil are boiled for 2 hours with a solution of 10 g. of sodium hydroxide in 100 ml. of alcohol in a flask fitted with a reflux condenser (fig. 81). The alcohol is then evaporated on a water bath, the sodium salts dissolved in water and the acids precipitated by the addition of sulphuric acid (1 : 1). These are washed thoroughly with water until free from sulphuric acid and dried by heating at 105°. The saturated and unsaturated acids are then separated by *Twitchell's method.** 25 g. of mixed acids are dissolved in 95 per

* J. A. C. S. 1921, 806. The older method based on the solubility of lead oleate in ether is more difficult, as emulsions difficult to break are usually formed.

cent (by volume) alcohol and to the well-stirred hot solution a similar solution of 8·5 g. crystallized lead acetate in 300 ml. of 95 per cent alcohol added. The mixture is allowed to cool to room temperature and kept at 15° for 2 hours, when the insoluble lead salts of the saturated acids are removed and washed with 95 per cent alcohol at 15°. These lead salts are further purified by dissolving in a boiling solution of 300 ml. of boiling 95 per cent alcohol containing 2 ml. of glacial acetic acid, cooling, filtering and washing with cold alcohol. On treating the insoluble lead salts with dilute nitric acid the free saturated acids are liberated. The soluble lead salts obtained by removing the alcohol from the alcoholic filtrate and decomposing with dilute nitric acid give the unsaturated acid, oleic acid, with small amounts of other acids. The oil is removed by means of a separating funnel, shaken with anhydrous calcium chloride, and purified by distillation under diminished pressure (fig. 9). B.p. 223° under 10 mm. pressure. Yield 10–15 g.

It is a clear oily liquid at ordinary temperatures, but solidifies on cooling. It melts at 14° and decomposes when distilled under ordinary pressure. $D_{4^\circ}^{15^\circ}$, 0·895.

The aqueous liquid after the removal of the oleic acid contains the second product of saponification, viz. the glycerol. On the factory scale this can be recovered but the extraction is difficult on the small scale.

Chemical properties.—Oleic acid is an unsaturated acid; thus it decolorizes bromine water and reduces alkaline permanganate solution. (Cf. allyl alcohol, Chap. X, C (*b*).) The lead salt is soluble in ether. Nitrous acid converts oleic acid into the stereo-isomeric elaidic acid. (Cf. stereo-isomerism of acids, Chap. XXXII, C.)

Experiment 66.—Elaidic acid from oleic acid.

5 g. of oleic acid are mixed with 1 to 2 ml. of dilute sodium nitrite solution, a little dilute nitric acid is added and the mixture shaken well. In a short time the oil changes into a solid which is removed and dried. M.p. 51°; b.p. 225° under 10 mm. pressure.

This acid is also unsaturated and decolorizes bromine water and alkaline permanganate solution.

E. The Hydrolysis of the Corresponding Nitrile
(S.B. Chap. IV, C. 5)

Method V.—Nitriles (cf. Chap. XIV, D) are readily hydrolysed to the corresponding acids on treatment with mineral acids or alkalis, e.g.:

$$C_6H_5 \cdot CH_2 \cdot CN + 2H_2O \rightarrow C_6H_5CH_2 \cdot CO_2H + NH_3.$$

Experiment 67.—Phenyl-acetic acid, $C_6H_5 \cdot CH_2 \cdot CO_2H$, **from benzyl chloride.***

15 g. of potassium cyanide (98 per cent) are dissolved in 15 ml. of water in a flask fitted with a reflux condenser. To the warm solution a mixture of 25 g. of benzyl chloride (Exp. 38) and 25 g. of alcohol is added, and the whole is heated on a boiling-water bath for three hours. The upper alcoholic layer is removed and distilled, the crude nitrile, b.p. 210–235°, being separately collected.

25 g. of this product and 75 g. of a mixture of concentrated sulphuric acid (3 volumes) and water (2 volumes) are heated in a flask fitted with a very long reflux condenser until the reaction just begins; the source of heat is then quickly removed. A very vigorous reaction takes place; when this has moderated, the mixture is heated for a few minutes longer. As the solution cools, the acid separates in the form of crystalline plates; when quite cold this is filtered with the aid of the pump, dissolved in sodium carbonate solution in order to remove a small amount of phenylacetamide, and reprecipitated by the addition of dilute sulphuric acid. It crystallizes from light petroleum as colourless plates; m.p. 76°; b.p. 265·5° (corr.). Yield, 90 per cent of theory.

For a further example of this method, cf. Exp. 321, *b*.

F. The Oxidation of Complex Carbon Compounds

Method VI.—Many complex oxygenated carbon compounds of the type of the carbohydrates yield oxalic acid when subjected to the action of vigorous oxidizing agents, especially concentrated nitric acid.

* *Mann*, B. 1881, **14**, 1645; *Staedel*, B. 1886, **19**, 1951.

Experiment 68.—Oxalic acid from cane sugar, $C_{12}H_{22}O_{11}$. (*To be conducted in a fume chamber.*)

40 g. of finely powdered cane sugar are added to 200 g. of concentrated nitric acid in a large flask. The mixture is warmed on a water bath until the reaction begins, after which it is allowed to proceed without the aid of external heat. Oxidation takes place with great vigour and abundant nitric fumes are evolved. When the reaction has moderated, the solution is evaporated on a water bath to a small bulk; on cooling, crystals of oxalic acid separate. These are filtered off on a porcelain funnel (a further yield is obtained by evaporating the mother liquor still further) and recrystallized from a little water. Yield about 10 g.

The acid forms colourless crystals ($H_2C_2O_4 \cdot 2H_2O$) which lose their water of crystallization when heated at 100–105°. M.p. (of hydrated crystals) 101·5°. It is soluble in water and alcohol, but only sparingly soluble in ether.

The acid and its salts, when heated with concentrated sulphuric acid, yield a mixture of carbon monoxide and carbon dioxide.

$$H_2C_2O_4 = H_2O + CO + CO_2.$$

Warm solutions of the acid (or its salts) decolorize acid solutions of potassium permanganate.

$$5H_2C_2O_4 + 2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 8H_2O + 10CO_2.$$

The calcium salt is insoluble in water and in acetic acid.

G. Kolbe's Synthesis of Hydroxy-acids of the Benzene Series.* (S.B. Chap. XXVI, A. 3)

Method VII.—The phenolic acids are formed when a current of dry carbon dioxide is passed over heated sodium phenoxides. The reaction takes place in three stages.

$$1.\ C_6H_5{\cdot}ONa + CO_2 \rightarrow C_6H_5{\cdot}O{\cdot}CO_2Na.$$

This reaction occurs when the phenate is heated in a stream of the gas at 110° for an hour. At a higher temperature (200°) intramolecular change takes place.

$$2.\ C_6H_5{\cdot}O{\cdot}CO_2Na \rightarrow C_6H_4\begin{cases} OH & (1) \\ CO_2Na & (2). \end{cases}$$

* *Kolbe*, A. 1860, **113**, 125; 1860, **115**, 201, &c.

The latter compound reacts with an unchanged molecule of sodium phenoxide, yielding the di-sodium derivative and free phenol.

$$3.\ C_6H_4\left\langle\begin{array}{l}OH\\CO_2Na\end{array}\right. + C_6H_5ONa \rightarrow C_6H_4\left\langle\begin{array}{l}ONa\ \ (1)\\CO_2Na\ (2)\end{array}\right. + C_6H_5OH.$$

In this reaction, therefore, only one-half of the phenol is converted into the acid; the remainder distils over unchanged.

In Schmidt's modification of the method,* the product of reaction (1) is heated in an autoclave under pressure of carbon dioxide at 130°, and is thereby converted directly into mono-sodium salicylate.

Experiment 69.—Salicylic acid.

$$C_6H_4\left\langle\begin{array}{l}OH\ \ \ (1)\\CO_2H\ (2)\end{array}\right., \textbf{ from phenol, } C_6H_5OH.$$

23·5 g. of pure phenol are added gradually to a solution of 10 g. of pure sodium hydroxide in a little water (15 ml.) contained in a porcelain or nickel dish. The mixture is evaporated over a free flame *with continual stirring*, the later stage being conducted with a large luminous flame kept in constant motion. The mass should be prevented from setting into a cake by stirring; when quite solid it is finely pulverized in a mortar, then heated in the nickel dish until quite dry, and quickly transferred into a dry tubulated retort which is immersed as far as possible in an oil or metal bath. Since the success of the experiment wholly depends on the sodium phenate being quite dry, it is advisable to heat the retort in the oil bath for half an hour at 140°, while a current of *dry* hydrogen is passed in through a leading tube fixed in the tubulure. The bath is then allowed to cool to 110°, and the hydrogen replaced by a current of dry carbon dioxide which is passed through the retort for about an hour. The temperature is then raised very gradually while a slow current of the gas is passed in, until at the end of four hours it reaches 200°, at which temperature the mixture is kept for two hours. The regenerated phenol is driven over into the neck of the retort during the later stages and is removed by warming gently with a flame. The fine powder left in the retort is poured into a beaker, dissolved in water, and treated with ex-

* J. pr., 1885 [2], 31, 397.

cess of concentrated hydrochloric acid. Salicylic acid crystallizes out on standing and is filtered off on a porcelain funnel, washed with water, and crystallized from hot water.

It is best purified by distillation with superheated steam * and forms colourless crystalline needles, m.p. 155°. It is sparingly soluble in cold water, more readily in alcohol, and is a powerful antiseptic.

The aqueous solution gives a violet coloration with ferric chloride (colour test for phenolic groups).

H. Recognition of Acids

It must be borne in mind that all sulphonic acids and many nitrophenols are acids and give most of the reactions of carboxylic acids.

If soluble in water, the aqueous solution of an acid usually gives an acid reaction with litmus solution. *Note.*—The fact that the aqueous solution has an acid reaction is no proof that the original substance was a free acid; it may have been an acid salt, an anhydride, chloride, or ester which was readily hydrolysed by water to the free acid; or it may have been the salt of a feeble base, e.g. aniline hydrochloride, as all such salts are largely hydrolysed by water yielding the free acid.

Acids insoluble in water should dissolve in cold dilute sodium carbonate solution with effervescence, leaving no oily or solid residue, such as would be given by the salts of aniline and its homologues. (Carry out the test with a small quantity of the substance on a watch-glass.)

To determine the actual acid present, reliance should be placed on physical constants rather than on mere colour reactions. The following should be determined: (*a*) The melting-point or boiling-point; (*b*) elements present; (*c*) the relative solubility in water; (*d*) whether a strong or a weak acid (test with various indicators); (*e*) the solubility or insolubility of the silver, calcium, barium, and ferric salts (for this purpose prepare a *neutral* solution of the ammonium salt by dissolving the acid in a very slight excess of ammonia solution, and boiling off excess of ammonia) (cf. Table X); (*f*) reducing properties (try the silver mirror test); (*g*) saturated or unsaturated nature (examine the action towards bromine water and towards acidified potassium permanganate).

* *Rautert*, B. 1875, 8, 537.

Finally, determine the equivalent of the acid by titration of a known weight of the acid in aqueous or alcoholic solution, with standard baryta solution, using phenol-phthalein as indicator (Chap. VII, A1); *or*, prepare and analyse the silver salt (Chap. VII, A2).

If a solution of an acid is given, attempts should be made to isolate the pure acid from the solution, by evaporation if the acid is not volatile, or by extraction with ether. Then the physical constants and equivalent should be determined. For physical constants of common acids, see Tables VII–X.

J. Removal of Carboxylic Groups

(*a*) The carboxylic group is invariably removed when the calcium salt of the acid is heated with lime (Exp. 13).

(*b*) In a few cases the carboxylic group is removed when the acid is boiled with water. One of the best examples of this is *s*-trinitrobenzoic acid, yielding *s*-trinitrobenzene.

(*c*) When two carboxylic groups are attached to the same carbon atom, one is readily eliminated by heating the acid above its melting-point, e.g. substituted malonic acids (Exp. 253). In some cases care is required during the hydrolysis of the esters of these dibasic acids, as elimination of carbon dioxide can occur during hydrolysis.

(*d*) By the electrolysis of an alkali salt of the acid (Exp. 14).

(*e*) In the aromatic series it is sometimes replaced by bromine if there is an ortho NH_2 or OH group present (cf. removal of sulphonic acid group, Chap. XII).

XIII. DERIVATIVES OF ACIDS

A. Metallic Salts

The metallic salts are formed by the substitution of metallic radicals for the hydrogen atoms of the carboxylic groups of the acid. When the acid is monobasic it gives rise, as a rule, to *normal* salts only. With polybasic acids *normal* and *acid* salts can be obtained:

$$CH_3{\cdot}CO_2H \rightarrow CH_3{\cdot}CO_2Ag$$

$$CO_2H{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H \begin{cases} \nearrow CO_2K{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2K \\ \searrow CO_2H{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2K. \end{cases}$$

Many dibasic acids do not form acid silver salts, e.g. succinic acid yields the normal salt, $CO_2Ag{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2Ag$, even when silver nitrate solution is added to a solution of the potassium hydrogen salt.

Method I.—When the acid and salt are both readily soluble in water, the simplest method for preparing the salt is by dissolving equivalent amounts of the acid and the metallic hydroxide or carbonate in small amounts of water, mixing and allowing to crystallize.

If the acid is available only in aqueous solution, the concentration of this solution must be determined by titration with standard barium hydroxide (Chap. VII, A1), using phenolphthalein as indicator. When the concentration is known, then the amount of metallic hydroxide or carbonate required to neutralize a given quantity of the solution can be calculated.

Experiment 70.—Potassium acetate.

A solution of 20 g. of glacial acetic acid in water is mixed with a warm, concentrated aqueous solution of the equivalent amount of pure dry potassium carbonate; crystals of the normal acetate, $CH_3{\cdot}CO_2K$, separate as the solution cools. These are filtered by means of the pump, and dried on a porous plate.

Method II.—When both acid and salt are soluble in water, but the metallic oxide, hydroxide, or carbonate is insoluble, the simplest method is to digest an aqueous solution of the acid with an *excess* of the oxide, hydroxide, or carbonate * on the water bath, to filter whilst hot through a fluted filter paper in a hot water funnel, and to allow the filtrate to cool.

Experiment 71.—Lead formate, $(H{\cdot}COO)_2Pb$.

Part of the acid distillate from Exp. 62 is digested on the water bath with an excess of lead carbonate, the solution filtered hot, and the filtrate allowed to cool. Long colourless prismatic crystals separate which can be readily filtered by means of a Büchner funnel, washed, and dried.

* It is generally safer to use the carbonate, as when an excess of the oxide or hydroxide is used there is the possibility that a basic salt may be formed. Thus from acetic acid and litharge the basic acetate, $CH_3{\cdot}CO{\cdot}O{\cdot}Pb{\cdot}OH$ can be obtained.

Experiment 72.—Determine the percentage of lead in the dried specimen of salt you have prepared:

(*a*) By ignition and conversion into oxide.
(*b*) By heating with sulphuric acid and weighing as sulphate.

Experiment 73.—Cupric formate, $(H{\cdot}COO)_2Cu, 4H_2O$.
The remainder of the aqueous distillate from Exp. 62 is digested with an excess of freshly precipitated cupric oxide which has been thoroughly washed. Ordinary cupric oxide powder may also be used, but the solution of the oxide will take longer. The hot filtrate when kept deposits large, transparent, blue prisms of the cupric salt.

Method III.—When the salt is sparingly soluble, or practically insoluble in cold water, the simplest method is to prepare the salt by double decomposition, using an aqueous solution of the ammonium salt of the organic acid and a solution of some soluble salt of the metal, usually the chloride or nitrate. The solution of the ammonium salt of the acid is prepared by taking a known weight of the acid, adding water and a *slight* excess of ammonium hydroxide, until the solution is faintly alkaline. If too much ammonia has been added, the excess may usually be removed by gently heating the solution. The salt is then precipitated by adding a slight excess of the metallic chloride or nitrate dissolved in water.

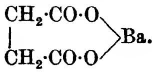
Experiment 74.—Silver benzoate, $C_6H_5{\cdot}CO_2Ag$.
Use 3 g. of benzoic acid purified by sublimation, prepare a solution of the ammonium salt and add a solution containing a slight excess of silver nitrate. Filter by means of the pump, wash with cold distilled water, and dry on a porous plate in a desiccator.

Experiment 75.—Determine the percentage of silver in the dry silver salt by ignition, and from the result of the experiment calculate the equivalent of benzoic acid (Chap. VII, B).

Experiment 76.—Cupric aminoacetate, $(NH_2{\cdot}CH_2{\cdot}CO_2)Cu, H_2O$.
2 g. of aminoacetic acid (glycocoll) are dissoved in 20 ml. of water and warmed in an evaporating dish on a water bath. 4 g. of copper carbonate are added gradually, with stirring, until effervescence ceases, the mixture warmed for some minutes, filtered, and the filtrate allowed to crystallize. It consists of dark blue needles.

Experiment 77.—Determine the percentage of cupric radical in the above hydrated salt by ignition and weighing the residual cupric oxide.

Experiment 78.—Barium succinate.



From 5 g. of succinic acid prepare a solution of the ammonium salt, add a very slight excess of barium chloride crystals, $BaCl_2, 2H_2O$, dissolved in water, filter, wash with distilled water until free from chloride, and dry in a desiccator.

Experiment 79.—Determine the percentage of barium radical in the dry salt by dissolving in hydrochloric acid, treating with sulphuric acid, and weighing the barium sulphate.

Experiment 80.—Preparation of the acid potassium salt of tartaric acid.

Dissolve 5 g. of crystallized tartaric acid, $CO_2H{\cdot}CH(OH){\cdot}CH(OH){\cdot}CO_2H$, in a small amount of warm water, and add the theoretical amount of potassium hydroxide solution (1 equivalent for 2 equivalents of acid). The sparingly soluble acid salt separates, and may be filtered, washed with a little water, and dried.

Acid Salts of Monobasic Acids.—As a rule, an inorganic monobasic acid yields normal salts only, but monobasic organic acids frequently yield both normal and acid salts, e.g. acetic acid gives the three salts, $KC_2H_3O_2$, $KH(C_2H_3O_2)_2$, and $KH_2(C_2H_3O_2)_3$. The majority of such acid salts are decomposed readily by water.

A dibasic acid can form a normal and several well-defined acid salts, e.g. oxalic acid gives the three salts: $K_2C_2O_4, H_2O$; KHC_2O_4; $KH_3(C_2O_4)_2, 2H_2O$.

Experiment 81.—Potassium salts of oxalic acid.

From oxalic acid prepare crystalline samples of each of the above-mentioned salts.

B. Salts of Organic Acids with Organic Bases

The combination of an amine (cf. Chap. XVIII) and an acid depends to a great extent on the strengths of the acid and base. Thus the simpler aliphatic amines combine readily with

most organic acids, but when weaker bases are used the salts are not always easily isolated.

Experiment 82.—Phenylammonium benzoate,* $C_6H_5{\cdot}CO{\cdot}O{\cdot}NH_3C_6H_5$.

$$C_6H_5NH_2 + C_6H_5CO_2H \rightarrow C_6H_5{\cdot}CO{\cdot}O{\cdot}NH_3C_6H_5.$$

Equivalent quantities of aniline and benzoic acid are stirred together in a test tube with a thermometer. The temperature rises as the mixture turns solid, showing that combination has taken place. The resulting salt is unstable, and is decomposed partially when crystallized from light petroleum. The decomposition can be avoided by recrystallizing from solvent containing 5 per cent of free aniline.

It consists of long, colourless, silky needles, m.p. 90°; it is fairly soluble in warm water, readily in most organic solvents.

C. Complex Salts: Co-ordination Compounds
(S.B. Chap. XLVI, A)

Many metallic radicals form complex salts in which organic radicals play an important part. The structure of such compounds can be represented with the aid of covalent and co-ordinate linkages.

They may be regarded as additive compounds of two small molecules, 4KCN, $Fe(CN)_2$ or $K_4FeC_6N_6$, but are usually represented as

$$\overset{++}{[Ni(C_5H_5N)_4]}\overset{--}{I_2},\quad \overset{++++}{K_4}\overset{----}{[Fe(CN)_6]},$$
$$\overset{+++}{K_3}\overset{---}{[Cr(C_2O_4)]} \text{ and } \overset{+++}{[Cr(CON_2H_4)_6]}\overset{---}{Cl_3},$$

where the groups within square brackets represent complex cations and anions.

Experiment 83.—Hexa-ureo-chromic chloride, $Cr(CON_2H_4)_6Cl_3, 3H_2O$.

10 g. of green chromic chloride hydrate, $CrCl_3, 6H_2O$, are dissolved by warming in 10 ml. water containing a few drops of hydrochloric acid. 14 g. of urea are added and the mixture evaporated on a water bath until solid begins to separate. It is then cooled and the solid product crystallized from a little

* *Lloyd* and *Sudborough*, J. C. S. 1899, **75**, 596.

water heated to a temperature not above 50°. Yield, 15–20 g. It consists of fine green needles; on treatment with the equivalent amount of sodium hydroxide a green precipitate of the corresponding hydroxide is obtained.

Experiment 84.—Potassium cobaltioxalate, $K_3[Co(C_2O_4)_3]$, $3H_2O$.*

25 g. freshly precipitated cobalt carbonate, 26·5 g. oxalic acid crystals, and 77·5 g. neutral potassium oxalate crystals are heated in a flask on a boiling-water bath with 500 ml. water with frequent shaking until all the carbonate has gone into solution. The solution is cooled to 40° and 30 g. of finely divided lead dioxide added gradually with continued shaking, followed by 25 ml. of glacial acetic acid added a drop at a time. The mixture is cooled in a bath of cold water during this addition and then allowed to stand for about an hour with frequent shaking (or continuous stirring). During this time the colour of the solution changes from red to deep green. The unused lead dioxide is filtered off and the complex salt precipitated by the addition of 500 ml. of rectified spirit. The dark green salt is filtered off and washed with alcohol and ether. Yield, 80 g.

It consists of dark green triclinic crystals which are sensitive to both heat and light. It can be recrystallized from warm water with addition of alcohol; if this is carried out at a temperature above 13·2°, the salt separates as enantiomorphous crystalline forms which can be separated by picking out.† Separation into optically active forms can best be carried out by means of an optically active base, e.g. strychnine.

D. Esters or Alkyl Salts

(S.B. Chaps. IV, C, VII, A)

The esters are derived from acids by the exchange of the replaceable hydrogen atoms of carboxylic groups for alkyl radicals, in the same manner as metallic salts result by exchanging the hydrogen for metallic radicals. Monobasic acids give rise to normal or neutral esters only; dibasic acids can give both normal and acid esters.

* *Thomas*, Complex Salts, Blackie & Son.

† *Werner*, B. 1912, 45, 865.

Normal Esters.

Method I.—By the action of the acid on the alcohol, e.g.:

$$\underset{\text{Acetic acid}}{CH_3CO_2H} + \underset{\text{Ethyl alcohol}}{HOC_2H_5} \rightleftharpoons \underset{\text{Ethyl acetate}}{CH_3CO_2C_2H_5} + H_2O$$

As the reaction is reversible, it is necessary in certain cases, in order to obtain a good yield, to use a dehydrating agent to take up the water formed during the reaction or to use an excess of one of the reagents, e.g. alcohol.

Experiment 85.—Ethyl acetate, $CH_3{\cdot}CO_2C_2H_5$.

A mixture of 95 per cent alcohol (50 ml.) and concentrated sulphuric acid (100 ml.) is placed in a half-litre flask fitted up as shown in fig. 78 and maintained in the oil bath at a temperature of 140°. At this temperature a mixture of equal volumes of alcohol and glacial acetic acid is run in from the dropping funnel * at the same rate at which the liquid distils over. After about 500 ml. of the mixture have been used, the distillate is treated as follows: To remove any acetic acid carried over, it is treated in a large beaker with a dilute solution of sodium carbonate, with continual stirring, until the upper layer of ester no longer shows an acid reaction. The mixture is then poured into a separating funnel and the lower aqueous layer run off, after which the ester is shaken with a strong solution of calcium chloride (100 g. in 100 ml. of water) to remove alcohol. The lower layer is again run off as completely as possible, and the ester dried by allowing to stand (preferably overnight) over granular calcium chloride. It is then filtered through a fluted filter paper into a dry distilling flask and distilled from a boiling-water bath in the usual manner, the portion boiling between 74° and 79° being collected separately. Yield, 80 per cent of theory. For further purification, see Chap. XXIV, A.

For the preparation of large quantities of the ester a method which can be made continuous for several days consists in using phosphoric acid (sp. gr. 1·75), heating to 160° and running in the same mixture as described above.

It is a colourless liquid, with a pleasant, fruity odour; b.p., 77°; $D^{17°}_{4°}$, 0·905. It is slightly soluble in water, but is miscible in all proportions with alcohol and ether.

* The dropping funnel has a long stem drawn to a fine point, which dips under the surface of the liquid in the flask, and the thermometer dips into the oil bath.

Experiment 86.—Methyl oxalate,* $\begin{matrix} COOCH_3 \\ \dot{C}OOCH_3 \end{matrix}$.

$$\begin{matrix} COOH \\ \dot{C}OOH \end{matrix} + 2CH_3OH = \begin{matrix} COOCH_3 \\ \dot{C}OOCH_3 \end{matrix} + 2H_2O.$$

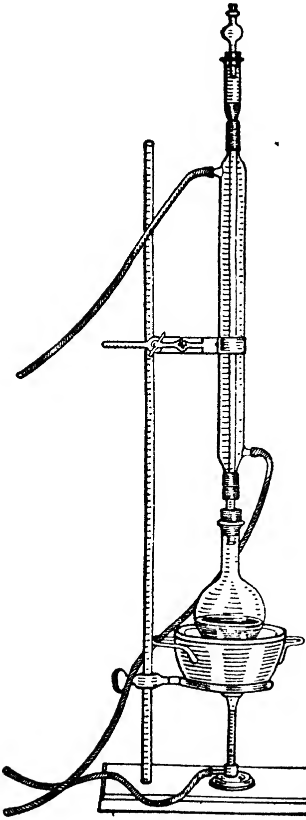


Fig. 81

50 g. of oxalic acid crystals are fine powdered, spread on a large clock-glass, and heated in an air oven to a temperature of 110–120° for about an hour, to remove the water of hydration. (Test when completed by ascertaining the loss of weight.)

The anhydrous acid is then heated in a reflux apparatus on a boiling-water bath (fig. 81), with 40 g. (excess) of pure methyl alcohol for two hours. The product is subjected to fractional distillation. When a temperature of 120° is attained the water condenser is replaced by an air condenser (fig. 82), and the distillate obtained above this temperature collected in a porcelain dish. As it cools it solidifies, and is separated from any remaining liquid by filtering over the pump and pressing on porous plate. The product is recrystallized from methyl alcohol or dilute alcohol, when it forms colourless crystalline plates, m.p. 54°, b.p. 163°. Yield, 15–20 g., i.e. 30–40 per cent of theory.

Method II.—**The Fischer-Speier Method.†** This consists in boiling the anhydrous acid with two to three times its weight

* *Erlenmeyer*, J. 1874, 572.

† B. 1895, 28, 3252.

of absolute alcohol in the presence of a small amount of concentrated sulphuric acid or dry hydrogen chloride, which act as catalytic agents in accelerating the reaction.

Experiment 87.—Ethyl benzoate, $C_6H_5 \cdot CO \cdot OC_2H_5$.

$$C_6H_5 \cdot CO\boxed{OH + H}OC_2H_5 \rightleftharpoons C_6H_5 \cdot CO \cdot OC_2H_5 + H_2O.$$

A mixture of 50 g. of pure benzoic acid, 100 g. of absolute ethyl alcohol, and 10 g. of concentrated sulphuric acid are boiled for three hours in a round-bottomed flask, attached to

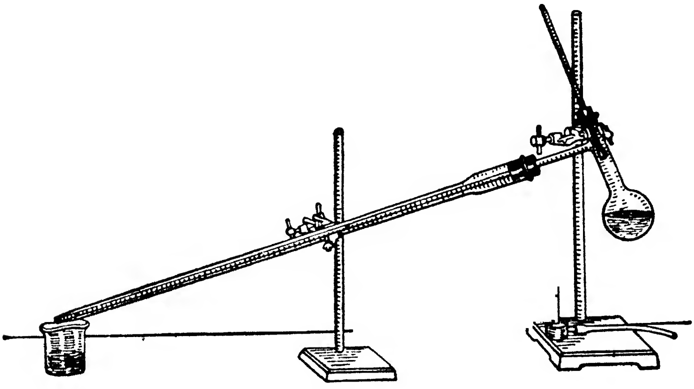


Fig. 82

a reflux condenser (fig. 80). The greater part of the alcohol is then distilled off, and the residue poured into about five times its volume of cold water. The liquid is neutralized with solid sodium carbonate and the oil extracted with ether. The ethereal solution is separated, dried with anhydrous potassium carbonate, the ether removed, and the residue distilled. 55 g. (i.e. 90 per cent of theory calculated on the amount of the acid used) pass over as a colourless liquid, b.p. 213°; D, 1·066. The ester is very slightly soluble in water, but is soluble in alcohol and ether.

Experiment 88.—Diethyl succinate, $CO_2Et \cdot CH_2 \cdot CH_2 \cdot CO_2Et$.

60 g. of succinic acid are treated with 100 ml. of 96 per cent alcohol and 4 ml. of concentrated sulphuric acid, and the mixture heated for three hours on a water bath in a flask fitted with a reflux condenser. After cooling, the product is

poured on to 30 g. of soda crystals in a beaker, the oil separated, washed with a little ice water, dried with calcium chloride, and distilled using an air condenser (fig. 82). The portion boiling between 200° and 220° is collected. Yield, 75–80 g., i.e. 90 per cent of theory.

It is a colourless oil with fragrant odour, and is insoluble in water. B.p., 216°; $D_{4°}^{25\cdot5°}$, 1·0475.

Experiment 89.—Diethyl tartrate, $CO_2Et\cdot(CHOH)_2\cdot CO_2Et$.

Dry hydrogen chloride (cf. Chap. XXXVIII) is led slowly into a flask containing absolute alcohol until an increase in weight of 3 per cent is obtained. To 100 g. of the resulting solution 20 g. of tartaric acid, which has been dried previously in an air oven at 110° for an hour, are added, and the mixture heated in a reflux apparatus on a water bath for six hours (fig. 81). The whole is then distilled under reduced pressure; ethyl alcohol and water pass over first, the temperature rises rapidly, and the greater portion passing over at 192–193°, under a pressure of 60 mm., is collected separately. Yield, 22 g., i.e. 80 per cent of theory.

It is a fragrant-smelling liquid, b.p. 280°/760 mm.; $D_{4°}^{14°}$, 1·2097. It is dextro-rotatory, $[\alpha]_D^{20°} = +7\cdot659$, and is sparingly soluble in water, but dissolves readily in alcohol and ether.

For determination of specific rotatory power, see Exp. 328.

The ordinary Fischer-Speier method for isolating the ester cannot be used in the above case as the ester dissolves in water and is readily hydrolysed to the acid and alcohol.

Alcoholysis.—A methyl ester can usually be transformed into the corresponding ethyl ester when it is dissolved in an excess of ethyl alcohol and a fragment of metallic sodium added.* The reactions which occur are those indicated in the equations:

$$R\cdot C\begin{matrix}\nearrow\!\!\!\!\nearrow O\\ \searrow OMe\end{matrix} + EtONa \rightarrow R\cdot C\begin{matrix}\nearrow ONa\\ - OEt\\ \searrow OMe\end{matrix} \rightarrow R\cdot C\begin{matrix}\nearrow OEt\\ \searrow\!\!\!\!\searrow O\end{matrix} + MeONa.$$

The change also occurs when a solution of an ester in a different alcohol is heated with 3 per cent hydrogen chloride,† but the transformation does not take place when a diortho-substituted benzoic ester is used.‡ The process is usually termed *alcoholysis.*

* *Purdie*, J. C. S. 1885, **47**, 855.
† *Patterson*, J. C. S. 1901, **79**, 280.
‡ *Sudborough* and *Davies*, P. 1905, **21**, 87.

Certain acids, especially diortho-substituted benzoic acids, are not esterified by the catalytic process. (Cf. Steric Retardation, S.B. Chap. XXXVI.) In such cases the esters may be obtained by Methods III or IV.

Method III.—By the action of the alcohol on the acyl chloride.

A good yield of ester can generally be obtained when the acyl chloride (Chap. XI, A2) is boiled for a short time with a slight excess of the alcohol and pyridine or α-picoline to combine with the hydrogen chloride formed.

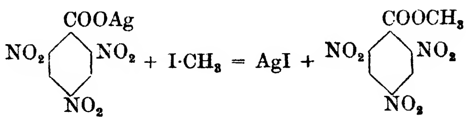
Experiment 90. — Menthyl cinnamate from cinnamoyl chloride.

$$C_6H_5{\cdot}CH{:}CH{\cdot}COCl + C_{10}H_{19}{\cdot}OH \rightarrow C_6H_5{\cdot}CH{:}CH{\cdot}CO{\cdot}OC_{10}H_{19} + HCl.$$

A known weight of cinnamic acid is heated in a reflux apparatus on a water bath with two equivalents of thionyl chloride until the evolution of hydrogen chloride ceases. The excess of thionyl chloride is then distilled off, the equivalent quantity of menthol added to the cinnamoyl chloride and the mixture heated in an oil bath at 120–130° for four hours. The product is steam-distilled to remove excess of menthol and then left in contact with dilute sodium carbonate solution for several hours. The oil is taken up with ether, the ethereal extract dried with anhydrous sodium sulphate, and the ether removed by distillation on a water bath. The product is a viscid oil which solidifies on long standing. Yield, 90 per cent. It is crystallized from light petroleum and has m.p. 32°.

Method IV.—A universal method of preparing esters is by the action of alkyl iodides on the silver salts of the acids; or in the case of methyl esters by the action of methyl sulphate * (2 mols) on an aqueous solution of the sodium salt of the acid; the mixture is shaken, warmed to 30–40°, and the ester removed.

Experiment 91. — Methyl trinitrobenzoate,† $(NO_2)_3C_6H_2{\cdot}COOCH_3$.



* *Werner* and *Seybold*, B. 1904, **37**, 3658; *Graebe*, A. 1905, **340**, 244.
† *Sudborough*, J. C. S. 1895, **67**, 600.

2 g. of trinitrobenzoic acid (1:2:4:6) are converted into the ammonium salt by the addition of the theoretical amount of ammonium hydroxide solution (excess is to be avoided as a deep-red solution is then formed.) A slight excess of silver nitrate in aqueous solution is added. The precipitated silver salt is removed, washed and dried in a desiccator. The dried salt and 4 g. of methyl iodide are placed in a small flask fitted with a reflux condenser and heated on a gently boiling water bath for an hour. The excess of methyl iodide is then distilled off, the residue extracted with boiling alcohol and filtered to remove silver iodide. As the solution cools, the ester separates in the form of yellow plates, m.p. 157°. Yield almost theoretical.

Method V.—Acid esters can be formed by the action of an olefine (mono-ene) on an acid. A simple example of this is the formation of ethyl hydrogen sulphate $C_2H_5HSO_4$ by absorbing ethylene in concentrated sulphuric acid. This is a reaction of considerable industrial importance as the olefines present in the gases from natural petroleum can be preferentially absorbed in sulphuric acid by varying the concentration of the acid and the temperature, and on hydrolysing the acid sulphates so formed, monohydric alcohols are obtained. With monobasic acids neutral esters are formed, e.g. *iso*-bornyl acetate from camphene (Exp. 346) and acetic acid.

Experiment 92.—*iso*-Bornyl acetate from camphene.

10 g. of camphene are dissolved in 25 g. of glacial acetic acid and 1 g. of 50 per cent sulphuric acid added. The mixture is warmed to 60° until a clear solution is obtained (2–3 hours), water is added and *iso*-bornyl acetate separates as an oil. It is dried with calcium chloride and distilled. Yield, 10 g., b.p. 112°/17 mm.

On hydrolysis (using alcoholic KOH) the ester yields the alcohol *iso*-borneol. M.p. 214°.

Acid Esters.

Acid esters derived from dibasic acids may be obtained:

Method I.—By partial esterification.

Experiment 93.—Ethyl hydrogen tartrate, $C_2H_5H{\cdot}C_4H_4O_6$.*

A solution of tartaric acid in an equal amount of absolute alcohol is heated for six hours at 65–70° in a water bath. The product is diluted with water and excess of barium carbonate added. The barium tartrate and excess of carbonate

* *Guérin Varry*, A. 1837, 22, 238.

are removed, the filtrate evaporated and allowed to crystallize. The barium ethyl tartrate which separates is dried and decomposed with the theoretical amount of dilute sulphuric acid. The filtrate from the barium sulphate, when evaporated gently, yields the ester as colourless rhombic prisms, m.p. 90°.

Method II.—By the addition of alcohol to the anhydride of a dibasic acid.

Experiment 94.—*iso*-Butyl hydrogen phthalate, $CO_2H{\cdot}C_6H_4{\cdot}CO_2C_4H_9$.

$$C_6H_4\left\langle\begin{matrix}CO\\CO\end{matrix}\right\rangle O + C_4H_9{\cdot}OH = C_6H_4\left\langle\begin{matrix}CO_2H\\CO_2C_4H_9\end{matrix}\right.$$

5 g. of phthalic anhydride (Exp. 100) are boiled with twice the theoretical weight of pure isobutyl alcohol for 45 min. The product is kept in a vacuum desiccator until the excess of alcohol is removed, and then crystallized from hot carbon disulphide, when the ester is deposited as glistening white plates, m.p. 58°. Yield almost theoretical.

Method III.—By the partial hydrolysis of the normal ester.

Experiment 95.—Ethyl hydrogen succinate,* $CO_2Et{\cdot}(CH_2)_2{\cdot}CO_2H$.

$$CO_2Et{\cdot}(CH_2)_2{\cdot}CO_2Et + KOH \rightarrow CO_2Et{\cdot}(CH_2)_2{\cdot}CO_2K + EtOH.$$

50 g. of diethyl succinate (Exp. 88) (1 mol.) are diluted with 40 ml. of alcohol in a large distilling flask, and treated with a strong solution of 16 g. of potassium hydroxide sticks in alcohol. The mixture becomes warm and some salt separates. After standing for 3 hours, the alcohol is distilled off on the water bath, a current of carbon dioxide being meanwhile passed through the apparatus. The residue is taken up with water, and the solution shaken up with ether to remove any unchanged diethyl ester. The aqueous solution contains potassium ethyl succinate (as required for Exp. 297); to obtain the free ester, it is acidified with hydrochloric acid and extracted with ether; the ethereal extract is dried, the ether evaporated, and the residue distilled under diminished pressure. B.p. 170° under 30 mm. Yield, 60–70 per cent of theory.

Ortho-esters.

The ortho-esters are to be regarded as the alkyl derivatives of the carboxylic acid hydrates (compounds of the type $R{\cdot}C(OH)_3$) and hence have the structure $R{\cdot}C(OR)_3$. When

* *Walker*, J. C. S. 1892, **61**, 709.

R = H we have the simplest ortho-ester, viz. ethyl orthoformate, $H\cdot C(OEt)_3$, a product obtained by the action of sodium ethoxide on chloroform, which may be regarded as the acid chloride of orthoformic acid. On hydrolysis the ortho-esters yield alcohol, water and the carboxylic acid. An interesting ester is ethyl ortho-carbonate $C(OEt)_4$, the ester of orthocarbonic acid $C(OH)_4$, i.e. $H_2CO_3 + H_2O$.

Experiment 96.—Methyl orthoformate, $H\cdot C(OMe)_3$, from chloroform.

10 g. of sodium are dissolved in 100 ml. of methyl alcohol, 15 ml. of chloroform added, and the mixture refluxed for 3 hours. The product is fractionally distilled and the highest fraction collected—a colourless liquid, b.p. 102°. On the hydrolysis with hot dilute sulphuric acid the ester yields methyl alcohol and formic acid.

Esters of Inorganic Acids.

Inorganic oxy-acids, e.g. nitric, nitrous, sulphurous, sulphuric and phosphoric, give alkyl derivatives both normal and acid in much the same manner as organic acids. Some of these are of commercial value, e.g. methyl sulphate as a methylating agent, amyl nitrite both in pharmacy and for certain types of diazotization, and cresyl phosphates as plasticizers in the paint industry.

The alkyl halides may be regarded as esters of the halogen hydracids or as halogen substitution products of the hydrocarbons. With oxy-acids the esters are usually isomeric with other substitution products of hydrocarbon, e.g. alkyl nitrites with nitroparaffins (Chap. XV, B), ethyl hydrosulphite with ethyl sulphonic acid (Chap. XVI, B).

Experiment 97.—Ethyl nitrite.

A mixture of 130 g. of commercial sodium nitrite (95 per cent), 57 ml. of 90 per cent alcohol, and water sufficient to make the total volume 500 ml. constitutes solution *a*. Solution *b* contains 57 ml. of 90 per cent alcohol, 51 ml. of sulphuric acid (sp. gr. 1·84) and water to make the volume up to 500 ml. Solution *a* is placed in a large wide-mouthed bottle (1½ to 2 litres capacity) fitted with a three-holed stopper carrying (i) a mechanical stirrer, (ii) a delivery tube, and (iii) a dropping funnel the stem of which reaches nearly to the bottom of the bottle. The delivery tube is connected to an absorption flask containing cooled alcohol or to a pair of large U tubes kept in a freezing mixture. Solution *b* is slowly run into the bottle

through the dropping funnel and a steady stream of gaseous ethyl nitrite dissolves in the cooled alcohol or is condensed in the cooled tubes to a colourless liquid, b.p. 17°.

The ester is usually prepared just before use but can be kept in alcoholic solution for some time.

Experiment 98.—*iso*-**Amyl nitrite.**

A mixture of 20 g. *iso*-amyl alcohol with 20 g. concentrated sulphuric acid is added little by little to a well-cooled solution of 16 g. of sodium nitrite in 10 ml. of water. The mixture is distilled until no more oily drops pass over. The lower aqueous layer of the distillate is removed, the ester dried with anhydrous calcium chloride and redistilled. Yield, 15 g.; b.p. 99°. The ester has a strong fruity odour.

E. Recognition of Salts

The majority of salts leave inorganic residues (metal, oxide, or carbonate) when ignited on platinum or porcelain. Ammonium salts are completely volatile, but can be readily distinguished by the fact that they yield ammonia when treated with *cold* potassium hydroxide or when rubbed with slaked lime. (Cf. amides and nitriles, Chap. XIV, B and D.)

To determine the nature of the metallic radical, examine the residue obtained after ignition of the substance either alone or with concentrated sulphuric acid. To determine the acid from which the salt is derived, prepare, if possible, a specimen of the pure acid, determine its physical constants (e.g. the melting-point, boiling-point), and the percentage of silver in the silver salt. If the acid is sparingly soluble in water, a specimen can be obtained readily by treating the salt, or better, an aqueous solution of the salt, with a mineral acid. If soluble in water, it can often be obtained by extracting the acidified solution with ether, and removing the ether after the solution has been dried.

For physical constants and characteristics of common acids, see Tables VII–X, Chap. XXXVII.

Colour reactions and solubilities of certain salts may be made use of, but should not be the only methods adopted.

F. Recognition of Esters

The esters are mostly volatile liquids with fruity odours, generally insoluble, or only sparingly soluble, in water. They

are hydrolysed by alkalis yielding the free alcohol and the alkali salt of the acid. The simplest method of treatment is to hydrolyse the ester with aqueous alkali and to determine the nature of the alcohol and acid formed.

The simplest and best method of hydrolysing the ester is to boil a given quantity of it with excess of 10 per cent aqueous potassium hydroxide in a flask fitted with a reflux condenser (fig. 81). If the ester is insoluble in water, the completion of the hydrolysis can be seen from the disappearance of the oily layer, unless the alcohol formed during the hydrolysis is also insoluble in water or potassium hydroxide solution (e.g. benzyl or amyl alcohol).

When the reaction is finished any oil is removed and its boiling-point taken, and it is examined in order to determine whether it is unaltered ester or an alcohol. If no oil is present, the product is partially distilled, using a water condenser, and when about one-third of the liquid has distilled over the distillation is stopped. The distillate will contain any volatile alcohol (e.g. methyl, ethyl, propyl), and the residue will contain the potassium salt of the acid.

Apply the special tests for methyl and ethyl alcohols given on p. 120 to the distillate.

Certain esters, particularly those of high molecular weight, are only slowly hydrolysed by aqueous potash, and in such cases it is advisable to use alcoholic (preferably methyl) potash. After boiling for 10 min. the methyl alcohol is distilled off, water is added, and the mixture treated as described under Saponification with Aqueous Potash.

To determine the acid, a small amount of the alkaline residue is acidified with hydrochloric acid.

(*a*) If a precipitate is formed, it indicates that the acid from which the ester is derived is insoluble in water. The whole residue is then acidified, the precipitated acid removed and examined carefully.

(*b*) If no precipitate is obtained, it indicates that the acid is soluble in water. The acidified mixture may be extracted with ether in order to obtain a specimen of the pure acid.

Many acids, e.g. oxalic, succinic, and polyhydroxy acids, e.g. tartaric, citric, saccharic, cannot readily be extracted with ether, and method (*c*) should be adopted.

(*c*) The acid may be recognized by means of (1) colour re-

actions; (2) solubilities of salts; (3) reducing properties. (Cf. Chap. XXXVII, Table X, properties of common acids.)

N.B.—In trying colour reactions and solubilities of salts, it must be remembered that the alkali used for the hydrolysis may not be pure, but may contain chloride, carbonate, &c.

XIV. DERIVATIVES OF ACIDS—(*Continued*)

A. Acid Anhydrides or Acyl Oxides

(S.B. Chaps. VII, C, XXVI, B)

1. **Anhydrides of Monobasic Acids.**—These are theoretically derived from the acids by the elimination of one molecule of water from two molecules of the acid; but they cannot be prepared by the action of dehydrating agents on the acids.

Modes of Formation.—By the action of the acyl chloride (Chap. XI, A) on the anhydrous sodium salt of the acid, e.g.

$$CH_3{\cdot}COCl + CH_3{\cdot}CO{\cdot}ONa \rightarrow (CH_3{\cdot}CO)_2O + NaCl.$$

By using the chloride and sodium salt of different acids, mixed anhydrides are produced, e.g.

$$CH_3{\cdot}COCl + CH_3{\cdot}CH_2{\cdot}COONa \rightarrow \begin{matrix} CH_3{\cdot}CO \\ C_2H_5{\cdot}CO \end{matrix}\Big> O + NaCl.$$

Experiment 99.—Acetic anhydride, $(CH_3CO)_2O$, **from acetyl chloride.**

The sodium acetate should be freshly dehydrated as described in Exp. 13, care being taken that no charring occurs during the process.

50 g. of anhydrous sodium acetate are introduced into a retort connected with a water condenser. A dropping funnel is fixed through the tubulure of the retort, and by means of the funnel 30 g. of acetyl chloride (Exp. 34) are added drop by drop. When the addition is completed, the dropping funnel is removed, the mixture stirred with a glass rod, and the tubulure closed with a glass stopper. The retort is then heated with a luminous flame kept in constant motion. The distillate is collected in a distillation flask, the side tube of which is fitted with a drying tube containing calcium chloride. A little

fused sodium acetate is added to the product, which is redistilled from the collecting flask into a flask protected from atmospheric moisture (fig. 78). It is a colourless liquid with suffocating odour, b.p. 138°; **D**, 1·073.

2. **Anhydrides of Dibasic Acids.**—Certain dibasic acids, e.g. succinic acid and its substituted derivatives and phthalic acid, yield cyclic anhydrides by the elimination of one molecule of water from one molecule of the acid.

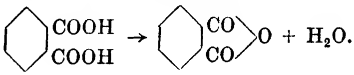
$$\begin{array}{l} CH_2\cdot CO\cdot OH \\ | \\ CH_2\cdot CO\cdot OH \end{array} = H_2O + \begin{array}{l} CH_2\cdot CO \\ | \\ CH_2\cdot CO \end{array}\!\!\!>O.$$

Succinic acid Succinic anhydride

The property seems to be characteristic of acids which can yield an anhydride containing a ring built up of five atoms.

Modes of Formation.—*Method I.—Formation of the anhydride by heating the acid.*

Experiment 100.—Phthalic anhydride from phthalic acid.



10 g. of phthalic acid (Exp. 58) are heated in a sublimation apparatus (fig. 19). The sublimate, which consists of long white needles, is the pure anhydride. M.p. 128°.

Method II.—Succinic acid does not yield the pure anhydrides on sublimation; the sublimates, in these cases, consist of mixtures of the anhydride with the original acid.* The anhydrides are obtained in a pure state by heating the acid with a dehydrating agent. Various dehydrating agents can be used, e.g. phosphorus pentachloride or oxychloride, acetyl chloride or acetic anhydride. The last is generally the most convenient.

Experiment 101.—Succinic anhydride from succinic acid.† (Cf. equation above.)

10 g. of finely powdered succinic acid are boiled for two hours with excess (15 g.) of acetyl chloride in a flask fitted with a reflux condenser. The product is poured into a shallow dish or clock-glass and kept in a desiccator over soda-lime until the excess of acetyl chloride and acetic acid are completely removed; it is then recrystallized from chloroform and forms long needles, m.p. 119°.

* *Volhard*, A. 1887, **242**, 148. † *Anschütz*, A. 1884, **226**, 8.

Experiment 102.—Camphoric anhydride from camphoric acid. 10 g. camphoric acid, 5 g. acetic anhydride, and a small piece of anhydrous zinc chloride are heated together in a reflux apparatus for 10 min. On cooling, the reaction mixture solidifies to a crystalline mass which is washed with cold water, dilute sodium hydroxide solution and again with water. The product can be crystallized from hot alcohol and forms long, colourless needles, m.p. 220°.

3. **Chemical Properties of the Acid Anhydrides.**—The acyl anhydrides of the aliphatic series are, for the most part, colourless liquids which are readily soluble in alcohol and ether: the corresponding compounds of the benzene series are solids, generally melting considerably lower than the acids from which they are derived. They are insoluble in water, but are gradually hydrolysed by it to the corresponding acid.

$$(CH_3{\cdot}CO)_2O + H_2O = 2CH_3CO_2H.$$

When treated with dilute alkalis they are readily converted into salts of the corresponding acids.

B. Acid Amides. (S.B. Chaps. VII E, X)

The acid amides are to be regarded as acids in which the hydroxyl groups of the carboxylic radicals ($-COOH$) have been replaced by the amido-group ($-NH_2$). Amides can also be obtained from sulphonic acids (Chap. XVI).

Modes of formation.—*Method I.—By the dehydration of the ammonium salt of the acid.**

Experiment 103.—Acetamide, $CH_3{\cdot}CONH_2$, from ammonium acetate.*

$$CH_3{\cdot}CO{\cdot}ONH_4 \rightarrow CH_3CO{\cdot}NH_2 + H_2O.$$

50 g. of glacial acetic acid are weighed into a large evaporating basin and warmed gently on a hot-water bath. Finely powdered ammonium carbonate is added gradually with continual stirring until the mixture just shows an alkaline reaction. (Dilute a small portion with water and test with litmus paper.) About 65–70 g. of ammonium carbonate will be necessary. The mixture is then heated on the water bath

* *Hofmann*, B. 1882, **15**, 979; *Rosanoff*, *Gulick*, and *Larkin*, C. N. 1911, **104**, 1. Alternative method described by *Hitch* and *Gilbert*, J. A. C. S. 1913, **35**, 1780.

until another test portion just shows an *acid* reaction. After cooling, the crystals are drained and pressed on filter paper.

50 g. of this ammonium acetate and 56 g. of glacial acetic acid are boiled in a litre flask with a reflux condenser for five hours, and the product is distilled rapidly. The distillate is then fractionated, using a simple form of column with two bulbs. *This operation should be carried out as slowly as possible.* Three fractions are collected: (1) the fraction passing over below 180°, (2) between 180° and 213°, (3) above 213°. The second fraction (180–213°) is again fractionated, and the portion passing over at about 213° added to fraction (3).

This fraction solidifies as it cools, and the crystals are dried by pressing between filter paper. Yield, 30 g., or 60 per cent of the theoretical. This method is much more convenient than the older Hofmann method, according to which the ammonium acetate was heated in sealed tubes. The acetic acid used appears to act as a catalyst.

The crystals of acetamide possess the peculiar odour characteristic of mouse excrement. This is not the odour of the pure substance, but of an impurity which accompanies it. The substance recrystallized from ether is odourless; it forms colourless crystals; m.p. 82°; b.p. 223°. It is deliquescent, soluble in water, alcohol, and ether.

Method II.—By the action of concentrated ammonia solution on acyl chlorides. This method is particularly suitable for the preparation of the amides of the higher fatty and of the aromatic acids.

Experiment 104.—Benzamide, $C_6H_5CO{\cdot}NH_2$, from benzoyl chloride.

$$C_6H_5COCl + 2NH_3 \rightarrow C_6H_5CO{\cdot}NH_2 + NH_4Cl.$$

5 g. of benzoyl chloride (Exp. 35) are added, *drop by drop*, to 20 ml. of strong ammonia solution (D, 0·880) contained in a beaker, or to 10 g. of solid ammonium carbonate. After cooling, the precipitated product is filtered with the aid of the pump, washed well with water, and dried on a porous plate. It crystallizes from hot water as colourless, glistening plates, m.p. 130°, b.p. 288°, and is readily soluble in hot water, alcohol, and ether. Yield, 4 g.

Aromatic sulphonamides.—The amides of aromatic sulphonic acids can be prepared in exactly the same manner.

$$C_6H_5SO_2Cl + 2NH_3 \rightarrow C_6H_5SO_2{\cdot}NH_2 + NH_4Cl.$$

For the preparation of *o*- and *p*-toluene sulphonamides, see Exp. 135.

Method III.—By the action of concentrated ammonia solution on esters. This method is used mainly for the preparation of amides which are not readily soluble in water, e.g. amides of certain dibasic acids. If the ester is a solid it may be dissolved in a little alcohol. Methyl esters react more readily than ethyl.

Experiment 105.—Oxamide from ethyl oxalate.

$$C_2H_5O{\cdot}CO{\cdot}CO{\cdot}OC_2H_5 + 2NH_3 \rightarrow NH_2{\cdot}CO{\cdot}CO{\cdot}NH_2 + 2C_2H_5OH.$$

3 g. of ethyl oxalate are added gradually to about 3 ml. of concentrated ammonia solution, and the mixture well shaken until the ester is transformed into a snow-white crystalline solid. The precipitate is filtered with the aid of the pump, washed with alcohol, and dried.

It is a white crystalline solid, which partly sublimes on heating, but the greater part is decomposed; it is very sparingly soluble in water and alcohol.

Experiment 106.—Succinamide from ethyl succinate.*

$$C_2H_5O{\cdot}CO{\cdot}(CH_2)_2{\cdot}CO{\cdot}OC_2H_5 + 2NH_3 = NH_2{\cdot}CO{\cdot}(CH_2)_2{\cdot}CO{\cdot}NH_2 + 2C_2H_5OH.$$

Proceed exactly as in Exp. 105. The product is recrystallized from hot water, and the crystalline needles dried in a steam oven.

It forms colourless needles, m.p. 242–243°, is sparingly soluble in cold water, more readily in hot, and is insoluble in absolute alcohol and in ether.

Chemical Properties of the Acyl Amides (S.B. Chaps. VII, E, XXVI, A1).—The acyl amides are generally crystalline substances with definite melting-points, and are therefore of use for the characterization of the acids from which they are derived. On the whole, they are less readily soluble in water than the ammonium salts of the corresponding acids.

As compared with amines (Chap. XVIII) they are only feebly basic. They form salts with strong acids, but these are readily decomposed into amide and acid in contact with water. The amides derived from very weak acids, e.g. urea, the diamide of carbonic acid, give fairly stable salts, e.g. urea nitrate, urea oxalate.

* *Fehling*, A. 1844, **49**, 196.

1. When boiled with alkalis they are completely hydrolysed, giving off ammonia.

$$X{\cdot}CONH_2 + KOH = X{\cdot}CO_2K + NH_3.$$

2. Treated with nitrous acid,* they yield the corresponding acid, with evolution of nitrogen. (Cf. Amines, Chap. XVIII.)

$$X{\cdot}CONH_2 + HNO_2 = X{\cdot}CO_2H + H_2O + N_2.$$

3. With bromine and alkali the acyl amides yield amines (Hofmann's reaction, Chap. XVIII, A1.)

Quantitative Estimation of Amido-groups.—The determination of the percentage of the amido-group ($\cdot NH_2$) in an amide is carried out as follows: A known weight of the amide is distilled with excess of strong potash solution, and the ammonia evolved absorbed in a known volume of standard hydrochloric acid. When completed, the excess of acid is titrated with standard alkali, using methyl orange as indicator (cf. Kjeldahl estimation of Nitrogen, Chap. V, C2).

Recognition of Amides.—The amides give off ammonia when boiled with dilute potassium hydroxide, but are not generally decomposed in the cold (cf. Ammonium salts). They are distinguished from ammonium salts and nitriles (this Chap., D) by examination of their comparative solubilities and melting-points.

To determine the specific amide, isolate and examine the acid formed by reactions 1 and 2 above, and if necessary determine the percentage of $-NH_2$ present.

C. Imides

Dibasic acids which yield anhydrides also form *Imides*, which may be regarded as anhydrides in which the $>O$ atom has been replaced by the divalent imido-group $>NH$.

Method I.—By the dry distillation of ammonium salts or amides of dibasic acids.

Experiment 107.—Succinimide from ammonium hydrogen succinate.†

$$\begin{array}{l} CH_2{\cdot}COOH \\ | \\ CH_2{\cdot}COONH_4 \end{array} = \begin{array}{l} CH_2{\cdot}CO \\ | \\ CH_2{\cdot}CO \end{array}\!\!>NH + 2H_2O.$$

* A solution of potassium or sodium nitrite is added, and then the mixture acidified with a dilute mineral acid.

† *Fehling*, A. 1844, 49, 198.

25 g. of succinic acid are dissolved in a small quantity of water, and neutralized with ammonia solution. Any excess of ammonia is boiled off, and then an equal quantity of succinic acid (dissolved in water) is again added. The solution is evaporated to dryness on a steam or water bath, and the residue dried in a steam oven. The dry salt is transferred to a retort and distilled quickly, using a *large luminous* flame. The sublimate is recrystallized from dry acetone, and forms colourless rhombic plates, m.p. 125–126°; b.p. 287–288°. Yield, 10–15 g.

Method II.—By the action of dry ammonia on an acid anhydride.

Experiment 108.—Phthalimide * from phthalic anhydride.

$$C_6H_4\left\langle\begin{array}{c}CO\\ \\ CO\end{array}\right\rangle O + NH_3 = C_6H_4\left\langle\begin{array}{c}CO\\ \\ CO\end{array}\right\rangle NH + H_2O.$$

20 g. of phthalic anhydride (Exp. 100) are placed in a large boiling tube, which is fitted with a cork bored with two holes, one carrying a leading tube which reaches to within 1 cm. of the substance. The tube is heated in an oil bath to 130°, while a current of dry ammonia is led in. The temperature of the bath is raised gradually until after about an hour it reaches 230°; the tube is then withdrawn, and the contents crystallized from ether. Yield, 12 g., i.e. 60 per cent of theory; m.p. 233°.

Chemical Properties of the Imides.—The imides resemble the amides in their behaviour towards hydrolysing agents. The properties of the :NH group are so modified by the proximity of the two carbonyl (:CO) groups that the imido-hydrogen is often replaceable by metallic radicals.

Experiment 109.—Potassium salt of phthalimide,†

$$C_6H_4\left\langle\begin{array}{c}CO\\ \\ CO\end{array}\right\rangle NK.$$

A quantity of phthalimide is dissolved in alcohol and treated with the theoretical amount of alcoholic potassium hydroxide solution. A white crystalline salt separates out, which is only sparingly soluble in water, and insoluble in alcohol and ether.

* This imide is an important synthetical agent for the preparation of various amino-compounds (*Gabriel*, cf. S.B. Chap. XXVI, B).

† *Landsberg*, A. 1882, **215**, 181.

Imides yield amino-acids when treated with bromine and alkali (*Hofmann's reaction*, cf. Exp. 148).

Quantitative Estimation of Imido-groups.—This is carried out in a similar manner to the estimation of amido-groups (p. 176).

For Substituted Amides and Imides, cf. Chap. XIX.

D. Nitriles or Alkyl Cyanides.

(S.B. Chap. IV, C5)

The nitriles or alkyl cyanides contain the monovalent $\cdot C\vdots N$ group attached to an alkyl radical.

Modes of Formation.—*Method I.*—*By the dehydration of an acid amide by means of phosphoric anhydride or phosphorus pentachloride.*

Experiment 110.—Acetonitrile from acetamide.*

$$CH_3CO{\cdot}NH_2 = CH_3{\cdot}CN + H_2O.$$

10 g. of dry acetamide (Exp. 103) are added to 15 g. of phosphoric anhydride in a small distilling flask. The substances are mixed by shaking, and the flask connected with a condenser. On warming gently with a small flame a vigorous reaction ensues: the acetonitrile is distilled over by means of a *large luminous* flame kept in constant motion. The distillate is treated with about half its volume of water, and then solid potassium carbonate is added until no more dissolves. The upper layer of nitrile is separated by means of a small tap funnel and redistilled with a little fresh phosphorus pentoxide from a small distilling flask. Yield, 5 g.

It is a colourless liquid with an agreeable odour, miscible with water, alcohol, and ether; b.p. 82°; $D_{4^\circ}^{15^\circ}$, 0·789.

Method II.—*From halogen derivatives by the action of potassium cyanide* (cf. Exp. 67).

Method III.—*By the addition of hydrogen cyanide to aldehydes* (cf. Exp. 321).

Method IV.—*By application of the diazo-reaction* (cf. Exp. 187).

General Chemical Properties of the Nitriles.—The nitriles are liquids, usually insoluble in water, possessing an ethereal odour, and distilling without decomposition. They are hydro-

* *Dumas*, A. 1847, 64, 332.

lysed when boiled with acids or alkalis or superheated with water yielding the corresponding acids or their salts, with evolution of ammonia, e.g.

$$CH_3{\cdot}CN + 2H_2O = CH_3{\cdot}CO_2H + NH_3.$$

Experiment 111.—Warm a few drops of acetonitrile with dilute potassium hydroxide solution until no more ammonia is evolved. Neutralize the resulting solution with hydrochloric acid, and test for an acetate (cf. Table X).

On reduction, the nitriles yield primary **amines,*** e.g.

$$CH_3{\cdot}CN + 4H \rightarrow CH_3{\cdot}CH_2{\cdot}NH_2 \text{ (ethylamine).}$$

Experiment 112.—Treat a solution of a few drops of a nitrile in alcohol with metallic sodium. Test the resulting solution for a primary amine by the carbylamine reaction (cf. Chap. XVIII, E).

Recognition of Nitriles.—The nitriles resemble the ammonium salts, amides, and amic acids (e.g. oxamic acid, $NH_2{\cdot}CO{\cdot}CO{\cdot}OH$), and cyano-acids (cyanacetic acid, $N{:}C{\cdot}CH_2{\cdot}CO_2H$), in their behaviour towards alkalis. The last two may readily be distinguished, since they possess the carboxylic group; the distinction between the others depends chiefly on a study of the physical constants of the substance and the identification of the acid obtained by hydrolysis.

XV. NITRO-DERIVATIVES—NITRATION

The reaction with nitric acid provides a fairly general method of distinguishing between aliphatic and aromatic compounds. As a rule, treatment of the former class of compounds with nitric acid leads to oxidation, whereas in the latter case nitro-derivatives containing the group $\cdot N\!\begin{array}{l} \diagup\!\!\!\diagup O \\ \diagdown\!\!\!\diagdown O\end{array}$ or $\cdot N\!\begin{array}{l} \diagup\!\!\!\diagup O \\ \searrow O\end{array}$ are produced, e.g.

$$\underset{\text{Benzene}}{C_6H_5\boxed{H + HO}\cdot N\!\begin{array}{l} \diagup\!\!\!\diagup O \\ \diagdown\!\!\!\diagdown O\end{array}} \rightarrow \underset{\text{Nitrobenzene}}{C_6H_5{\cdot}N\!\begin{array}{l} \diagup\!\!\!\diagup O \\ \diagdown\!\!\!\diagdown O\end{array}} + H_2O.$$

* *Mendius*, A. 1862, **121**, 129.

One or more nitro-groups may enter the molecule, according to the conditions of the experiment and the nature of the compound to be nitrated. The introduction of subsequent nitro-groups after the first becomes progressively more difficult, and the number of nitro-groups that can be introduced into a closed-ring compound is usually limited (cf. Preparation of nitrophenols, Exp. 116, and picric acid, Exp. 118). When the aromatic compound contains a saturated side chain, nitration usually affects the benzene ring; under special conditions only (e.g. heating with dilute nitric acid, sp. gr. 1·075, in a sealed tube at 105° for several hours) does the nitro-group enter the side chain.*

A. Nitration of Aromatic Compounds

For the preparation of aromatic nitro-derivatives the following reagents are usually employed:

If the substance is readily nitrated: dilute nitric acid, sodium or potassium nitrate and diluted sulphuric acid; solutions of nitric acid in glacial acetic acid, ether, acetone, or acetic anhydride.†

If the substance is nitrated with moderate ease: concentrated nitric acid.

If the substance is nitrated with difficulty, or if di- or tri-nitro-derivatives are required: fuming nitric acid: a mixture of concentrated nitric and sulphuric acids; a mixture of fuming nitric and concentrated sulphuric acids.

A solution of nitric acid in concentrated sulphuric acid is very frequently used, and is highly efficient as a nitrating agent. It probably contains the compound $SO_2\langle\begin{smallmatrix}OH \\ O{\cdot}NO_2\end{smallmatrix}$.

The methods may be further modified by (*a*) varying the temperature, (*b*) varying the amount of nitric acid employed.

Experiment 113.—Nitrobenzene, $C_6H_5{\cdot}NO_2$, from benzene.

100 g. of concentrated nitric acid (sp. gr. 1·4) are added gradually to 150 g. of concentrated sulphuric acid, the mixture is cooled, and then added in small portions to 50 g. of pure benzene contained in a 500 ml. flask. The contents of the flask are well shaken and cooled, after each addition, by

* *Konowaloff*, B. 1894, **27**, Ref. 194.
† *Orton*, J. C. S. 1902, **81**, 806.

immersion in cold water; under no circumstances must the temperature be allowed to rise above 50°, otherwise some dinitrobenzene is formed. When the addition is completed, a vertical air condenser is attached to the flask, which is then immersed in a water bath kept at 50–60° for about an hour. The flask is withdrawn from the bath at intervals and shaken well. After cooling, the contents of the flask are poured into a separating funnel, and the *lower* layer of acid removed. The oily nitrobenzene is washed free from acid by shaking, once with water, then with dilute sodium carbonate solution, and again with water. (During these operations the nitrobenzene forms the *lower* layer.) The liquid is now turbid, and is freed from water by allowing to stand over granular calcium chloride until it becomes clear. It is then fractionally distilled from a distilling flask provided with a long air condenser (fig. 82); the fraction boiling between 204° and 207° is collected separately.

The nitrobenzene is a yellow oil with an odour of bitter almonds. It solidifies in a freezing mixture to a solid. M.p. 3°; b.p. 206–207°; $D^{15°}$, 1·208. Yield about 65 g., i.e. 80 per cent of theory.

When the compound to be nitrated already contains a substituent group, the position taken by the nitro-group depends on the nature of that group. (Cf. S.B. Chap. XXXVII.) The presence of alkyl radicals in the benzene nucleus facilitates nitration, so that the nitro-derivatives of toluene, xylene, and mesitylene are more readily prepared than the nitro-derivatives of benzene.

With chlorobenzene the first NO_2 enters the 2 or 4 position, and on further nitration 2:4-dinitrochlorobenzene is formed. With nitrobenzene the second NO_2 group takes up the 3 position, and on further nitration *s*-trinitrobenzene is the product. With benzoic acid the products are 3-nitro- and then 3:5-dinitrobenzoic acids.

Experiment 114.—*m*-Dinitrobenzene from nitrobenzene.*

$$C_6H_5{\cdot}NO_2 \rightarrow C_6H_4\begin{cases} NO_2\ (1) \\ NO_2\ (3) \end{cases}$$

20 g. of nitrobenzene are added gradually to a mixture of 40 g. of concentrated sulphuric acid and 35 g. of fuming nitric

* *Muspratt* and *Hofmann*, A. 1846, 57, 214.

acid, contained in a 1000 ml. flask, with continual shaking. The mixture is heated on a boiling-water bath until a test portion poured into water separates as a solid cake (about half an hour is required). It is then poured, while still hot, into a large quantity of cold water. The dinitrobenzene which solidifies is filtered off on a porcelain funnel, washed with cold water, and dried on a porous plate. Yield about 24 g., i.e. almost theoretical. The product, which is a mixture of the three isomeric dinitrobenzenes (mainly the meta- compound), is crystallized from alcohol, when the meta-dinitrobenzene separates as pale-yellow flat needles, m.p. 90°.

Experiment 115.—3:5-Dinitrobenzoic acid, $C_6H_3(NO_2)_2{\cdot}CO_2H$, from benzoic acid.

100 g. of concentrated sulphuric acid are added to a solution of 20 g. benzoic acid dissolved in 33 ml. nitric acid (sp. gr. 1·52) and the whole heated on the water bath for 12 hours. The mixture is then cooled and poured on to ice, and the solid product filtered, washed, and dried. The dry product is again nitrated with a mixture of the two acids as given above, and the final product is crystallized from hot water. Yield theoretical; m.p. 206°.

The chloride of this acid, $C_6H_3(NO_2)_2COCl$, is a reagent used in characterizing alcohols and phenols, and is usually prepared in small quantities as required. It is a solid; m.p. 74°.

The presence of phenolic hydroxy-groups considerably facilitates nitration. In order to obtain mono-nitro-derivatives of phenol, dilute nitric acid must be employed.

Experiment 116.—*o*- and *p*-Nitrophenols from phenol.*

$$C_6H_5{\cdot}OH \rightarrow OH{\cdot}C_6H_4{\cdot}NO_2 \text{ (1:2 and 1:4).}$$

60 g. of dry sodium nitrate crystals are introduced into a large beaker of 1½ litre capacity and dissolved in 150 ml. of water. 75 g. of concentrated sulphuric acid are added gradually and the mixture cooled in running water. A warm solution of 40 g. of phenol in 5 g. of alcohol is added gradually to the mixture from a tap funnel. During the addition the acid mixture is stirred vigorously (automatically), and the temperature must not be allowed to rise above 25°. It is kept overnight, when the product collects as a dark oil (or solid) at the bottom of the vessel, and consists of a mixture of *o*- and *p*-nitrophenols with much tarry matter. It is freed from

* *Hart*, J. A. C. S. 1910, 32, 1105.

acid by shaking three or four times with cold water and decanting. About 250 ml. of fresh water are then added and the mixture subjected to steam distillation (fig. 10). The *o*-nitrophenol passes over with the steam and condenses as a yellow solid in the condenser tube, from which it is periodically removed by turning off the supply of cold water and allowing the water in the condenser to become warm. The distillation is continued as long as solid passes over: the product is then filtered by means of the pump and dried on a porous plate. The product is practically pure, but may be crystallized from dilute alcohol, and is thus obtained as bright-yellow needles, m.p. 45°. Yield, 15 g.

The aqueous liquid remaining in the flask, which contains much *p*-nitrophenol in solution, is removed while hot, and the tarry residue extracted three or four times with boiling water or with hot dilute hydrochloric acid (about 100 ml. at a time). The united extracts are decolorized by boiling with about 20 g. of animal charcoal for half an hour, filtered while hot through a fluted filter paper, and made alkaline by addition of sodium hydroxide solution. The liquid is evaporated down to a small bulk (about 100 ml.); if tarry matter separates it is removed by filtration. It is then acidified (while hot) with concentrated hydrochloric acid and allowed to cool. *p*-Nitrophenol separates in the form of long, almost colourless needles, which are filtered off and recrystallized from hot water. Yield about 8 g. M.p. 114°.

Preparation of Salts of Nitrophenols.—The nitrophenols are much more strongly acidic than the phenols (cf. Chap. XVII), and can decompose metallic carbonates.

Experiment 117.—Prepare crystals of potassium *o*-nitrophenate and sodium *p*-nitrophenate by dissolving the respective phenols in concentrated hot solutions of the metallic carbonates and allowing to crystallize.

The final product of the nitration of phenol is picric acid, $C_6H_2(OH)(NO_2)_3$(1:2:4:6), which is also formed when *o*- and *p*-nitrophenols are further nitrated.

Experiment 118.—Picric acid (*s*-trinitrophenol), $OH{\cdot}C_6H_2(NO_2)_3$, 1:2:4:6, **from phenol.**

10 g. of phenol are dissolved in 20 g. of concentrated sulphuric acid by warming in a porcelain basin. The product (phenol-sulphonic acid) is cooled and then added gradually to 50 g. of concentrated nitric acid (sp. gr. 1·4) in a 500 ml.

flask. A considerable amount of heat is generated during the operation and oxides of nitrogen are abundantly evolved. After the reaction has moderated the mixture is heated on a boiling-water bath for two hours. On cooling, picric acid separates as a yellow crystalline mass. The liquid is diluted with water and the crystals are filtered off at the pump, well washed with cold water, and recrystallized from hot water, when it is obtained in the form of yellow needles. It is sparingly soluble in cold water, but dissolves readily in hot water and in alcohol. Yield, 15 g., i.e. 60 per cent of theory; m.p. 122·5°.

Picric acid is more strongly acidic than the mono-nitrophenols. It is largely used as an explosive.

The presence of nitro-groups ortho to other groups often modifies the activities of these. Thus chlorine substituents in the benzene nucleus are often rendered very reactive by the presence of two, or even one, ortho-nitro-groups and become readily replaceable by OH, OMe, NH_2, NHR, &c. Similarly the presence of the nitro-groups in *s*-trinitrophenol imparts pronounced acidic properties to the compound. As an acid, picric acid is comparable with such a strong acid as oxalic. The acid chloride, picryl chloride, $C_6H_2Cl(NO_2)_3$, can be prepared by the methods given in Chap. XI, A2, or by the further nitration of 1-chloro-2:4-dinitro-benzene (*Frankland* and *Garner*).* An interesting method of formation is by the action of *p*-toluenesulphonyl chloride and diethylaniline on picric acid.

Experiment 119.—Picryl chloride.

A mixture of picric acid (11·5 g.), *p*-toluenesulphonyl chloride (9·5 g.), freshly distilled diethylaniline (8 g.), and nitrobenzene (9 g.) is heated for 8 hours on the water bath. The mixture is then acidified, steam distilled to remove nitrobenzene, and the solid crystallized from alcohol. M.p. 83°. Yield, 9–10 g.

B. Aliphatic Nitro-Compounds

Aliphatic nitro-compounds are usually prepared indirectly (see Exp. 120), but numerous cases of direct substitution have been carried out with dilute nitric acid under pressure. Such compounds as nitroethane, nitropropane, &c., are now produced in large quantities by the direct method.† The usual

* J. S. C. I. 1920, 164, R.

† *Worstall*, Am. 1898, **20**, 202; 1899, **21**, 211.

indirect method is by the action of an alkyl iodide on dry silver nitrite.*

Experiment 120.—Nitro-ethane, $C_2H_5 \cdot NO_2$, from ethyl iodide.

$$C_2H_5I + AgNO_2 \rightarrow C_2H_5 \cdot NO_2 + HgI.$$

The silver nitrite is prepared by adding a slight excess of a lukewarm concentrated solution of potassium nitrite to a similar solution of silver nitrate and allowing the mixture to cool. The precipitate of silver nitrite is collected on a filter, washed rapidly, and dried on a porous plate.

42 g. of dry silver nitrite are placed in a round-bottomed flask fitted with a reflux condenser, and 34 g. of ethyl iodide are added gradually through the condenser tube. During the process the flask is not disturbed, as it is important that the silver nitrite should be gradually penetrated by the iodide. The latter is admitted at such a rate that the liquid boils vigorously, but not too violently. The mixture is finally warmed for some time on the water bath, and the products separated by fractional distillation. Ethyl nitrite ($C_2H_5 \cdot O \cdot N:O$, isomeric with nitro-ethane), b.p. 18°, distils over first, and afterwards nitro-ethane is collected at 110–114°. Yield, 50 per cent of theory. It is a colourless liquid, b.p. 113–114°; $D^{13°}$, 1·058.

C. General Characteristics of the Nitro-Compounds

1. The aliphatic nitro-derivatives and the aromatic compounds with the nitro-group in the side chain are acidic in properties, with the exception of the tertiary nitro-derivatives, i.e. compounds of the type $R_1R_2R_3C \cdot NO_2$, which are neutral compounds.

Experiment 121.—To about 2 ml. of a solution of sodium ethoxide in absolute alcohol add a few drops of nitro-ethane. A white precipitate appears, which consists of the sodium derivative, $CH_3 \cdot CH:N\begin{smallmatrix} \nearrow O \\ \searrow O \cdot Na \end{smallmatrix}$.

These metallic derivatives are explosive when dried. Their structure is different from that of the parent compound, and they are thus pseudo-acids (cf. S.B. IV C, XX, LXXI J).

* *V. Meyer*, A. 1874, 171, 18.

2. The simpler nitro-compounds of the aromatic series are, for the most part, pale-yellow liquids or solids of high boiling-point, which distil unchanged and are often volatile with steam. With increase in the number of nitro-groups the colour deepens to an intense yellow or red, and the compounds decompose on heating, often explosively. All these nitro-compounds are heavier than water, and only sparingly soluble in it; most are readily soluble in alcohol, ether, and glacial acetic acid.

3. Nitro-compounds when reduced in acid solution, e.g. by the action of tin and hydrochloric acid, are converted into the corresponding primary amines (see Exp. 150).

$$\underset{\text{Nitro-ethane}}{C_2H_5{\cdot}NO_2} \rightarrow \underset{\text{Ethylamine}}{C_2H_5{\cdot}NH_2}$$

$$\underset{\text{Nitrobenzene}}{C_6H_5{\cdot}NO_2} \rightarrow \underset{\text{Aniline}}{C_6H_5{\cdot}NH_2}$$

These can be tested for by the carbylamine reaction (p. 226), or recognized by the melting-point of their acetyl or benzoyl derivatives (cf. Chap. XIX).

4. Reduction of a nitro-compound in neutral solution, e.g. boiling the nitro-body with zinc and water, yields a hydroxylamine derivative (Exp. 269).

$$C_6H_5{\cdot}NO_2 \rightarrow \underset{\text{Phenyl hydroxylamine}}{C_6H_5{\cdot}NH{\cdot}OH}$$

Experiment 122.—Heat a nitro-compound for a few minutes in a test tube with zinc dust and water. Filter and test the clear filtrate by warming with *Fehling's solution* (p. 372). A precipitate of cuprous oxide is formed indicating the presence of a hydroxylamine derivative, a compound which possesses reducing properties.

Additive Compounds.—The polynitro-compounds, e.g. *s*-trinitrobenzene, trinitrotoluene, picric acid, styphnic acid (*s*-trinitroresorcinol) and also picryl chloride, form well-defined coloured crystalline compounds with polycyclic aromatic hydrocarbons, phenolic ethers and arylamines. Picric and styphnic acids form definite salts with amines as they are strong acids, but with phenolic ethers and polycyclic hydrocarbons they form the same type of additive compound as does trinitrobenzene. Picryl chloride can also form the same type of product, but with primary and secondary amines it can also form condensation products by the elimination of hydrogen

chloride, e.g. picryl chloride and aniline can yield 2:4:6-trinitrodiphenylamine,

$$C_6H_2Cl(NO_2)_3 + C_6H_5{\cdot}NH_2 \rightarrow C_6H_5{\cdot}NH{\cdot}C_6H_2(NO_2)_3.$$

The salts and additive compounds are frequently used for identifying aromatic hydrocarbons, phenolic ethers and arylamines, as they crystallize well and have definite melting-points.

Experiment 123.—Prepare the additive compounds of (*a*) naphthalene and picric acid, (*b*) α-naphthylamine and trinitrobenzene, by dissolving equivalent quantities in alcohol or benzene and allowing to crystallize.

Elimination of the Nitro-Group from an Aromatic Nitro-Compound.—The nitro-derivative is reduced to an arylamine (Exp. 150), and the amino-group subsequently eliminated by means of the diazo-reaction (Exps. 197, 198).

D. Determination of the number of Nitro-Groups present in a Molecule *

The percentage of nitro-radical can be determined in many cases by estimating the amount of stannous chloride required to reduce the nitro- to amino-groups.

$$X{\cdot}NO_2 + 3SnCl_2 + 6HCl = X{\cdot}NH_2 + 3SnCl_4 + 2H_2O.$$

The stannous chloride is best used in the form of a solution of stannous ammonium chloride ($SnCl_2$, $2NH_4Cl$, $6H_2O$), which can be standardized by titration with iodine solution. (See Chap. XXXVIII for preparation.)

$$2SnCl_2 + 2I_2 = SnCl_4 + SnI_4.$$

A known weight of the nitro-compound (0·2–0·4 g.) is dissolved in 40 ml. of alcohol in a reflux apparatus fitted with an inlet tube for carbon dioxide. The air in the apparatus is removed by passage of carbon dioxide, and a known volume (excess) of stannous chloride solution introduced. The mixture is heated on a boiling-water bath for 2½ hours, cooled, and made up to 200 ml. with distilled water. The excess of stannous chloride is then titrated with decinormal iodine solution, using starch solution as indicator.

* *Callan, Henderson* and *Strafford*, J. S. C. I. 1920, **39**, 86, T. (resumé of methods); *Bruce*, C. N. 1919, **118**, 133.

Knecht and Hibbert * describe an alternative method using titanous chloride as reducing agent. Both methods fail in certain cases (e.g. *p*-nitro-naphthalene) where chlorination takes place as well as reduction. This error may be avoided by the use of titanous sulphate.†

If the molecular weight of the nitro-compound is known, the number of nitro-groups present in the molecule may be readily calculated.

Experiment 124.—Determine the percentage of nitro-radical in *m*-dinitrobenzene.

XVI. SULPHONIC ACIDS—SULPHONATION

A. Aromatic Sulphonic Acids

(S.B. Chap. XXIII)

One of the characteristic properties of benzene and its derivatives is the readiness with which they react with sulphuric acid, yielding sulphonic acids. The process is termed sulphonation, and the products contain the monovalent group, $SO_2{\cdot}OH$, e.g.

$$C_6H_5\boxed{H + HO}{\cdot}SO_2{\cdot}OH = C_6H_5{\cdot}SO_2{\cdot}OH + H_2O.$$

The reaction proceeds with varying degrees of readiness in the case of different substances, one or more sulphonic groups being introduced into the compound according to the conditions under which the reaction is conducted. The chief agents used for sulphonation are—concentrated sulphuric acid, fuming sulphuric acid, sulphuryl chloride, $HO{\cdot}SO_2{\cdot}Cl$, and mixtures of sulphuric acid with other dehydrating agents, e.g. acetic anhydride.

For the isolation of the products, the fact that the sulphonic acids generally form soluble calcium, barium, or lead salts is utilized. The strongly acid liquid, consisting of the sulphonic acid with excess of sulphuric acid, may be poured into excess of cold water containing pieces of ice. Under these circumstances a few sulphonic acids will crystallize. If

* *New Reduction Methods in Volumetric Analysis.*

† J. S. C. I. 1920, 86 T.

the product is soluble in water and no separation occurs, the hot solution is digested with excess of calcium or barium carbonate (or lead carbonate or oxide may be used), and filtered whilst hot to remove the precipitated sulphate. The calcium, barium, or lead salt of the sulphonic acid is then allowed to crystallize from the solution.

To obtain the free sulphonic acid, the recrystallized salts are decomposed with the calculated quantity of sulphuric acid, the precipitated sulphate filtered off, and the solution evaporated. Solutions of lead salts may be decomposed by hydrogen sulphide, and an aqueous solution of sulphonic acid obtained by filtering off the precipitated lead sulphide.

Experiment 125.—Benzene-sulphonic acid,* $C_6H_5{\cdot}SO_2{\cdot}OH$.

120 g. of fuming sulphuric acid of D 1·88–1·89 (containing 5–8 per cent of SO_3) are placed in a small flask fitted with a reflux condenser, and 30 g. of benzene are added gradually with continual shaking, care being taken that the first quantity of benzene dissolves before any further amount is added. During the addition the flask is cooled by immersion in cold water; after all the benzene has dissolved (about fifteen minutes are required) the product is treated in different ways according to whether a salt or the pure acid is required.

(*a*) **Sodium benzene-sulphonate,** $C_6H_5{\cdot}SO_2{\cdot}ONa$. The reaction mixture is added very slowly by means of a tap funnel to 400 ml. of a saturated solution of common salt contained in a stout beaker immersed in ice-cold water. After some time, or more quickly if the sides of the beaker are rubbed with a glass rod, sodium benzene-sulphonate separates in the form of glistening plates. After standing for several hours the crystals are filtered off (use a Buchner funnel and pump) and washed with a little saturated salt solution. Yield, 75 g.

The substance may be freed from common salt by recrystallization from absolute alcohol, in which sodium chloride is insoluble. The crude salt also contains sulpho-benzide, $(C_6H_5)_2{:}SO_2$, which can be removed by extracting the dried salt with ether.

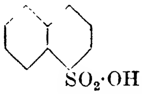
(*b*) **Benzene-sulphonic acid.**—To obtain the free acid the reaction mixture is poured into a large excess of water (½ litre) and neutralized by the gradual addition of excess of finely powdered barium carbonate made into a cream with water. The product is warmed and filtered quickly while hot through

* *Gattermann*, B. 1891, **24**, 2121.

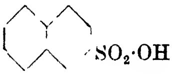
a fluted filter paper. The barium benzene-sulphonate, $(C_6H_5SO_2 \cdot O)_2Ba$, is deposited as the solution cools (evaporate down if necessary), and is purified by recrystallization from hot water. To obtain the free benzene-sulphonic acid, a quantity of the salt is treated with its exact equivalent of dilute sulphuric acid, the precipitated barium sulphate filtered off, and the sulphonic acid obtained by evaporating the solution to a small bulk and allowing the acid to crystallize.

Sulphonic acids can be very readily prepared by using poly-sulphates, i.e. compounds of acid sulphates with sulphuric acid of the type $NaH_3(SO_4)_2$, instead of sulphuric acid itself.* Mono-, di-, and tri-sulphonic acids can be prepared by the use of this reagent, e.g. benzene-1:3-di- and benzene-1:3:5-tri-sulphonic acid.

Naphthalene Sulphonic Acids.—Naphthalene yields two mono-sulphonic acid derivatives,



Naphthalene α-sulphonic acid



Naphthalene β-sulphonic acid

A mixture of the two acids is obtained when naphthalene is heated at 80° with concentrated sulphuric acid. They may be separated by fractional crystallization of their calcium or barium salts, as the β-sulphonates are less soluble than the α-salts. The α-salt or acid is transformed into the β-compound when heated with concentrated sulphuric acid, so that the chief product obtained by sulphonating naphthalene at 160° is the β-acid.

Experiment 126.—Naphthalene-β-sulphonic acid.†

60 g. of concentrated sulphuric acid are warmed in a round-bottomed flask, and 50 g. of finely powdered naphthalene added gradually, the flask being well shaken. The mixture is heated in a paraffin or metal bath (without condenser) at 170–180° for four hours. After cooling, the product is carefully poured into a litre of water, and the unaltered naphthalene which separates removed by filtration. The liquid is made alkaline with milk of lime, prepared by slaking quicklime (calculate the amount necessary to neutralize the sulphuric acid taken) with hot water. The mixture is filtered while hot through a damp filter-cloth, and the precipitate in the

* *Lambert*, D. R.-P. 113, 784. † B. 1870, 3, 195.

cloth thoroughly squeezed out into another dish. It is then boiled up with 500 ml. of water, and again filtered and pressed. The united filtrates are clarified by passing through an ordinary filter paper, then evaporated to a small bulk and allowed to stand overnight. The crystalline calcium salt [$(C_{10}H_6SO_2{\cdot}O)_2Ca$] which separates is filtered at the pump, washed with a little water, and finally dried on a porous plate. Yield variable.

Preparation of sodium naphthalene-β-sulphonate, $C_{10}H_7{\cdot}SO_2{\cdot}ONa$.

$$(C_{10}H_7{\cdot}SO_2{\cdot}O)_2Ca + Na_2CO_3 = CaCO_3 + 2C_{10}H_7{\cdot}SO_2{\cdot}ONa.$$

A portion of the calcium salt is dissolved in hot water, and a concentrated solution of the theoretical weight of anhydrous sodium carbonate added, until a test portion filtered off gives no further precipitate with sodium carbonate solution. After cooling, the precipitated calcium carbonate is filtered off, and the solution evaporated until crystals begin to form. After standing for several hours the crystals of sodium salt are filtered; a further yield of crystals is obtained by evaporating the mother liquor and allowing it to stand. The crystals are dried in a steam oven. Yield about 70 per cent of theory.

Preparation of the free naphthalene-β-sulphonic acid.—A portion of the calcium salt is treated with rather less than the theoretical amount of sulphuric acid diluted with five times its volume of water and warmed on a water bath. The aqueous solution of the acid obtained after filtering is evaporated to a small bulk on a water bath, when non-deliquescent plates, m.p. 161°, are deposited. The acid is not volatile with steam.

When the substance to be sulphonated already contains a substituent group, the position taken by the $\cdot SO_2{\cdot}OH$ group (or groups) depends on the nature of the group already present (cf. S.B. Chap. XXIII).

Alkyl-, amino-, and hydroxy-derivatives of benzene are sulphonated more readily than benzene itself. In the case of aniline, the final product is the *p*-sulphonic acid, $NH_2{\cdot}C_6H_4{\cdot}SO_2{\cdot}OH$, but several intermediate products are formed.* (Cf. S.B. Chap. XXIII).

Experiment 127.—Sulphonation of aniline. Preparation of sulphanilic acid, *p*-aminobenzene-sulphonic acid.

$$C_6H_5{\cdot}NH_2 \rightarrow NH_2{\cdot}C_6H_4{\cdot}SO_2{\cdot}OH\ (1{:}4).$$

* *Bamberger*, B. 1897, 30, 2274.

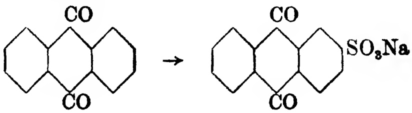
80 g. of concentrated sulphuric acid are placed in a round-bottomed flask, and 25 g. of aniline added cautiously. The mixture, consisting of aniline sulphate with excess of sulphuric acid, is heated in an oil or paraffin bath at a temperature of 180–190°, until a test portion diluted with water and treated with sodium hydroxide solution remains clear and no aniline separates (four to five hours are necessary). The product is then cooled, and poured gradually with stirring into excess of cold water, when the sulphanilic acid separates as fine greyish crystals. These are removed and recrystallized from hot water to which a little animal charcoal has been added to remove the colour. Yield about 25 g.

It forms colourless rhombic crystals containing 2 molecules of water of hydration. The substance has no definite melting-point, but decomposes at high temperatures.

Experiment 128.—Sulphonation of camphor, $C_{10}H_{6}O$; *d*-**camphor-10-sulphonic acid,** $C_{10}H_{15}O{\cdot}SO_2{\cdot}OH$ * (*Reychler's acid*). (S.B. Chap. LVII, C).

30 g. of powdered camphor are added gradually to a mixture of 20 g. of concentrated sulphuric acid with 40 g. of acetic anhydride. The camphor dissolves readily, and the mixture is allowed to stand for two to three days at the ordinary temperature, during which *d*-camphor-sulphonic acid crystallizes out. The liquid is then drained away from the crystals, which are filtered at the pump over a pad of asbestos or glass wool; they are washed with acetic acid till colourless, and purified by recrystallization from acetic acid or ethyl acetate. Yield, 16–18 g., i.e. 50 per cent of theory. It is thus obtained as large prisms, which decompose at 190–193°. The acid is optically active (dextro-rotatory $[\alpha]_D = +21°$), and is used for the resolution of *d-l* or *r* bases.

Experiment 129.—Sodium anthraquinone-2-sulphonate (*silver salt*) **from anthraquinone.**†



25 g. of finely powdered anthraquinone (Exp. 232) are added to 25 g. of fuming sulphuric acid containing 45–50 per cent

* *Reychler*, Bull. 1898, (iii), 19, 120; *Armstrong* and *Lowry*, J. C. S. 1902, **81**, 1442. † *Graebe*, *Liebermann*, A. 1871, **160**, 130; 1882, **212**, **44**.

SO_3 (sp. gr. 1·98–2) in a round-bottomed flask. The mixture is heated in an oil bath, the temperature of which is gradually raised so that at the end of an hour it reaches 160° The product is carefully poured into excess of hot water, and the unchanged anthraquinone which separates removed by filtration. The filtrate is neutralized with sodium hydroxide and cooled, when the greater portion of the sodium anthraquinone-sulphonate ($C_{14}H_7O_2{\cdot}SO_3Na, H_2O$) crystallizes out. A further yield of crystals is obtained by concentrating the filtrate. Yield, 20 g.

The final filtrate contains the sodium salt of anthraquinone-disulphonic acid, which may be obtained (mixed with sodium sulphate) by evaporating to dryness. It is best isolated as potassium salt by pouring the sulphonated product into a saturated solution of potassium chloride.

Anthraquinone-1-sulphonic acid * can be prepared in a similar manner by the addition of 2 per cent of mercuric sulphate to the sulphuric acid.

The sulphonic acids derived from amino- and hydroxy-derivatives of benzene, naphthalene and anthracene are compounds of considerable importance in the manufacture of dyes.

B. Aliphatic Sulphonic Acids. Modes of Formation

(S.B. Chap. IV, C4)

Method I.—These aliphatic acids cannot be obtained by direct sulphonation, but are usually prepared by the oxidation of mercaptans or by the action of alkyl iodides on metallic sulphites.

Experiment 130.—Ethyl-sulphonic acid, $C_2H_5{\cdot}SO_2{\cdot}OH$.†

$$2C_2H_5I + 2(NH_4)_2SO_3 + 2H_2O = 2C_2H_5{\cdot}SO_2{\cdot}OH + 2NH_4OH + 2NH_4I.$$

20 g. of ethyl iodide are added to a solution of 20 g. of crystallized ammonium sulphite in 40 ml. of water, in a flask attached to a reflux condenser. and the mixture boiled until all the ethyl iodide has disappeared (about six hours are necessary). The liquid is then diluted with water, 30 g. of

* *Schmidt*, B. 1904, **37**, 67. † *Hemilian*, A. 1873, **168**, 146.

lead oxide added, and the mixture heated until all ammonia has been expelled. When cold the lead iodide is removed by filtration, and the lead salt of ethyl-sulphonic acid, $(C_2H_5SO_2O)_2Pb$, which is present in the filtrate, decomposed by passing hydrogen sulphide until no more precipitate is formed. The lead sulphide is filtered off, and the solution of ethyl-sulphonic acid neutralized by addition of excess of barium carbonate (20 g.). After filtration, the clear solution of barium ethyl sulphonate is evaporated. Yield, 22 g., 90 per cent of theory.

For a number of years the constitution usually attributed to the additive compounds of aldehydes and ketones with sodium bisulphite (cf. Exp. 209) was that of sulphonic acid salts:

$$R{\cdot}C\begin{matrix}\diagup H\\ \diagdown\!\!\diagdown O\end{matrix} + NaHSO_3 \rightarrow R{\cdot}CH\begin{matrix}\diagup OH\\ \diagdown SO_2{\cdot}ONa.\end{matrix}$$

The additive compounds are now supposed to contain the grouping R·CH(OH)(O·SO·ONa).*

Method II.—Metallic sulphites also form additive compounds with certain olefine derivatives.†

$$R{\cdot}CH{:}CH{\cdot}CO_2H + K_2SO_3 \rightarrow R{\cdot}CH_2{\cdot}CH\begin{matrix}\diagup CO_2K\\ \diagdown SO_3K.\end{matrix}$$

Experiment 131.—Phenylsulphopropionic acid from cinnamic acid.

Molecular proportions of cinnamic acid (Exp. 284) and normal potassium sulphite are boiled in a reflux apparatus with ten times their weight of water for twelve hours, allowed to cool, and acidified with acetic acid. A colourless crystalline precipitate of the acid potassium salt, $C_6H_5{\cdot}CH_2{\cdot}CH\begin{matrix}\diagup CO_2H\\ \diagdown SO_3K\end{matrix}$, separates and is recrystallized from hot water. A further yield of the product may be obtained by evaporating the filtrate, extracting the potassium acetate with alcohol, and crystallizing the residue from water.

The salt may be crystallized from boiling dilute hydrochloric or sulphuric acids without decomposition. When heated, it melts and decomposes with the development of aromatic odours.

* *Knœvenagel*, B. 1904, **37**, 4059; *Reinking*, *Dehnel*, and *Labhardt*, B. 1905, **38**, 1069.

† *Valet*, A. 1870, **154**, 63.

C. Characteristics of the Sulphonic Acids

The sulphonic acids are colourless oils or solids, generally hygroscopic and readily soluble in water. They are *strong* acids, the basicity depending on the number of sulphonic groups present. They are not hydrolysed when boiled with aqueous alkalis or acids (cf. the alkyl hydrogen sulphites, isomeric with the aliphatic sulphonic acids), but are decomposed when fused with alkalis, the aliphatic compounds yielding alcohols, and the aromatic, phenols or phenolic derivatives (cf. Exp. 138).

$$2C_2H_5SO_2{\cdot}OK + 2KOH = 2C_2H_5OH + K_2SO_3 + H_2O + SO_2$$
$$C_{10}H_7SO_2{\cdot}ONa + NaOH = C_{10}H_7OH + Na_2SO_3.$$

They give rise to salts, esters, acid chlorides, amides, anilides, &c., in much the same way as the carboxylic acids. The acids, as a rule, have no definite melting-points, and hence to diagnose the different acids it is usual to convert the sodium salts into the sulphonic chlorides (cf. Exp. 36), and then into the sulphonamides (cf. Exp. 135), as these latter are easily crystallized and have definite melting-points.

D. Removal of the Sulphonic Acid Group

The sulphonic acid group $\cdot SO_2{\cdot}OH$ can be removed from many, although by no means from all sulphonic acids, by heating the compound with superheated steam.

Experiment 132.—Removal of the sulphonic acid group from a derivative of sulphanilic acid; Preparation of 2:6-dibromaniline from 2:6-dibromo-1-amino-benzene-4-sulphonic acid.*

$$NH_2{\cdot}C_6H_2Br_2{\cdot}SO_3H + H_2O \rightarrow NH_2{\cdot}C_6H_3Br_2 + H_2SO_4.$$

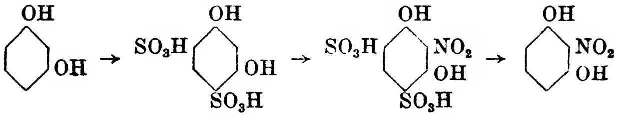
A mixture of 90 g. of concentrated sulphuric acid, 26 g. of water, and 20 g. of dry dibromo-sulphanilic acid (Exp. 43) is heated in a flask by means of an oil bath to 170°. The flask is fitted with a cork bored with three holes, for the steam inlet and outlet tubes and for the thermometer. It is not advisable to have the thermometer dipping directly into the acid, but to protect it by means of a glass tube closed at the lower end and passing through the cork. Superheated

* *Heinichen*, A. 1889, **253**, 275.

steam (p. 14) is blown through the solution, and the temperature rises gradually to 178°, but on no account must it rise above 180°. Part of the dibromaniline passes over with the steam, and is collected in the condenser and receiver. The greater part remains in the flask, and may be obtained by pouring the contents of the flask into cold water after the steam has passed through for one and a half hours. Yield, 83 per cent of theory.

The dibromaniline crystallizes from light petroleum in colourless needles, m.p. 83–84°.

Experiment 133.—Removal of the sulphonic acid groups from 2-nitro-1:3-dihydroxybenzene-4:6-disulphonic acid. Preparation of 2-nitro-resorcinol.*



22 g. of finely divided resorcinol (1:3-dihydroxy-benzene) are added gradually to 150 g. of fuming sulphuric acid (sp. gr. 1·875). When all is dissolved, the solution is allowed to cool and the disulphonic acid separates in a crystalline form. To the semi-solid mass, which is cooled by means of running water, and agitated by means of a mechanical stirrer, a mixture of 12·6 g. of nitric acid (sp. gr. 1·52) and 40 g. of fuming sulphuric acid (sp. gr. 1·875) is added gradually, care being taken that the temperature is kept between 10° and 15°. The mixture becomes yellow coloured, and ultimately a clear solution is obtained. After some time, 60 ml. of water are added for each 100 g. of the mixture; the whole is then heated and distilled with superheated steam (as in Exp. 132). 2-nitro-resorcinol passes over with the steam, and, after crystallization from dilute alcohol, is obtained in the form of orange-red needles, m.p. 85°.

E. Estimation of the Number of Sulphonic Acid Groups in the Molecule

If the molecular weight of the substance has been determined, and no carboxylic groups are present, the number of

* *Kaufmann* and *de Pay*, B. 1904, **37**, 725.

sulphonic acid groups can be determined in most cases by direct titration with standard alkali, and then calculating the number of grams of $\cdot SO_3H$ in one gram-molecule of the acid.

F. Derivatives of Sulphonic Acids

As stated in section C, the sulphonic acids give rise to derivatives of the same type as those obtained from the carboxylic acids, e.g. acid chlorides, acid amides and esters, but there are important differences between the two series of compounds. The acid chlorides of the sulphonic acids are more stable than the corresponding acyl chlorides, e.g. they are not readily decomposed by water. Again, the sulphonamides are not readily decomposed by concentrated alkali, and the sulphonic esters react readily with alcohol, yielding free acid and ether:

$$R\cdot SO_2\cdot OEt + EtOH \rightarrow R\cdot SO_2\cdot OH + Et_2O.$$

For preparation of a chloride, see Exp. 36.

An aromatic sulphonyl chloride can often be prepared directly by the action of chlorosulphonic acid, $Cl\cdot SO_2\cdot OH$, on the hydrocarbon, e.g. benzene and the chlorosulphonic acid yield benzene-sulphonic chloride.*

$$C_6H_6 + 2ClSO_3H \rightarrow C_6H_5\cdot SO_2Cl + H_2SO_4 + HCl.$$

Experiment 134.—*o*- and *p*-Toluenesulphonic chlorides from toluene.

100 g. toluene are added gradually to 400 g. of chlorosulphonic acid contained in a large beaker provided with a mechanical stirrer and immersed in a freezing mixture (ice and salt). Under no circumstances should the temperature be allowed to rise above 5°. After the addition the beaker is placed in a refrigerator for 12 hours or longer with occasional stirring, after which the mixture is poured carefully and slowly on to powdered ice. The sulphonic chlorides separate in liquid form; the aqueous acid is decanted off and the oil washed with water. After 12 hours more in the refrigerator the *p*-compound crystallizes while the *o*-isomer remains oily. They are separated by suction through a porcelain funnel provided with a thin layer of asbestos fibre.

* For details see Org. Synth. 1930, 10, 6.

The solid *p*-compound is purified from adhering *o*-compound by crystallization from ether. M.p. 69°.

The oily fraction consists of a mixture of about 70 per cent of the *o*- and 30 per cent of the *p*-compound. A pure sample of the former can be obtained by distillation under diminished pressure; b.p. 126° under 10 mm. pressure.

Experiment 135.—*p*-Toluenesulphonamide from *p*-toluenesulphonic chloride.

A weighed amount of the sulphonic chloride is placed in a reflux apparatus with twice its weight of solid ammonium carbonate and ten times its weight of water, and heated on a water bath until all the oil disappears. The amide separates out as white crystalline flakes. Yield, 90 per cent; m.p. 137°.

The oily fraction obtained in Exp. 134 may be treated similarly to yield a mixture of *o*-toluenesulphonamide (70 per cent), and the *p*-compound (30 per cent). The former being less soluble in water than the latter, a separation of the isomers may be carried out by crystallization from a large volume of hot water. *o*-Toluenesulphonamide separates out on cooling as white flaky crystals. M.p. 156°.

On oxidation with potassium permanganate in slightly alkaline solution *o*-toluenesulphonamide yields *saccharin*, which is a cyclic imide of *o*-sulphobenzoic acid, $C_6H_4(CO_2H)(SO_3H)$.

$$C_6H_4\left\langle\begin{matrix}CH_3\\SO_2\cdot NH_2\end{matrix}\right. + 3O \rightarrow C_6H_4\left\langle\begin{matrix}CO\\SO_2\end{matrix}\right\rangle NH + 2H_2O.$$

Experiment 136.—Saccharin from *o*-toluenesulphonamide.

A beaker (200 ml.) is arranged in a water bath and provided with a stirrer. 50 ml. water, 1·4 g. NaOH, and 5 g. *o*-toluenesulphonamide are placed in the beaker and stirred while the temperature of the bath is raised to 50°. 9·0 g. $KMnO_4$ crystals and 10 ml. of 20 per cent sulphuric acid are added and the stirring continued for 8–9 hours, the temperature being kept at about 50°. 100 ml. of hot water are then added and the precipitated manganese dioxide filtered off at 80–90°. The filtrate is cooled and saturated with CO_2, whereby any unoxidized amide is precipitated and is filtered off. Addition of sulphuric acid precipitates the saccharin. Yield, 85 per cent; m.p. 220°; when completely pure it has m.p. 227°.

The hydrogen atoms of the amido-group in sulphonamides are readily replaceable by alkali metals and by halogens, &c.

An important derivative of *p*-toluenesulphonamide is chloramine-T, $CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}N(Cl)Na,\ 2H_2O$.

Experiment 137.—Chloramine-T from *p*-toluenesulphonamide.

A volume of dilute sodium hydroxide solution (N.) is saturated with *p*-toluenesulphonamide. Chlorine gas is passed through the filtered solution, and a crystalline precipitate is obtained which is filtered off and dried by means of a water pump.

Chloramine-T is an important chlorinating agent and disinfectant. A molecular proportion on treatment with hydrochloric acid releases two equivalents of chlorine:

$$CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}N(Cl)Na,\ 2H_2O + 2HCl \rightarrow CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}NH_2 + NaCl + Cl_2.$$

A further important use of *p*-toluenesulphonamide is in the preparation of 1-amino-derivatives of the anthraquinone series from the corresponding chloro-compounds. (See Aminoanthraquinone, Exp. 154.)

XVII. PHENOLS AND PHENOLIC ETHERS
(S.B. Chap. XXIV)

The phenols are the aromatic hydroxy-derivatives in which the hydroxy-group is directly attached to the benzene nucleus, e.g. $C_6H_5{\cdot}OH$, $CH_3{\cdot}C_6H_4{\cdot}OH$, &c. Isomeric with certain phenols are the aromatic alcohols (S.B. Chap. XXV), in which the hydroxy-groups are attached to carbon atoms of side chains (cf. Exp. 24).

The phenols are classified as mono-, di-, tri-hydric, &c., according to the number of hydroxy-groups present in the molecule.

A. Modes of Formation

*Method I.—By fusion of sulphonic acids with alkali hydroxides,** e.g.

$$C_6H_5{\cdot}SO_2{\cdot}ONa + NaOH \rightarrow C_6H_5{\cdot}OH + Na_2SO_3$$
$$C_6H_5{\cdot}OH + NaOH \rightarrow C_6H_5{\cdot}ONa + H_2O.$$

* *Kekulé; Wurtz.*

The product formed in each case is the sodium derivative of a phenol, from which the phenol is liberated by the addition of a mineral acid. The acid also decomposes the sulphite, producing considerable amounts of sulphur dioxide, so that the decomposition should be carried out in a well-ventilated fume chamber.

Substances which contain two or more sulphonic acid radicals yield polyhydric phenols when fused with potash, and halogen derivatives of mono-sulphonic acids also yield dihydric phenols when fused in the same manner. It does not necessarily follow that the hydroxy-groups occupy the same relative positions in the molecule as the original sulphonic acid or halogen radicals, since, at the high temperature at which the reaction occurs, *molecular rearrangement* can readily take place. Thus all three chlorobenzene-sulphonic acids yield *m*-dihydroxy-benzene (resorcinol) when fused with potash. Constitutional formulæ based on the products of fusion with potash are liable to be incorrect, on account of the fact that molecular rearrangement often occurs at the high temperatures employed (cf. S.B. Chap. XXIV, A).

Experiment 138.—β-Naphthol, $C_{10}H_7{\cdot}OH$, **from sodium naphthalene-β-sulphonate.***

90 g. of fairly pure sodium hydroxide powder are treated with about 3 ml. of water in a large nickel or copper crucible (about 8–10 cm. diameter and 12–15 cm. deep). The crucible is heated carefully and the contents stirred, the stirrer consisting of an iron tube closed at one end and fixed into a cork at the other, so that when the iron tube gets hot the cork protects the hand. A little mercury is poured into the tube and a thermometer immersed in it; the temperature of the fused mass can by this means be determined with accuracy. It is advisable to cover the hand with a glove or duster during stirring, for molten caustic soda is inclined to sputter.

When the temperature of the fused caustic soda reaches 280°, 30 g. of sodium naphthalene-β-sulphonate (Exp. 126) are added gradually in portions of 5 g. After each addition the temperature is allowed to reach 280° before the next portion is added. When all has been introduced the temperature is raised; this is accompanied by much frothing and evolution of steam, and at 310° the reaction begins. This temperature is maintained for about ten minutes, and the mixture becomes

* *Schäffer*, A. 1869, **152**, 280.

completely liquid and separates into two layers. The molten mass is then poured on to a copper or iron tray and allowed to solidify. The solid is broken up, dissolved in 500 ml. of water, and treated gradually with concentrated hydrochloric acid until the liquid becomes acid to litmus, in order to transform the sodium β-naphtholate into the free phenol. When cold, the precipitated β-naphthol is filtered off, washed with a little water, and recrystallized from hot water. It forms colourless plates, m.p. 122°, b.p. 286°. Yield about 15 g., i.e. 80 per cent of theory.

Special Test.—A few drops of ferric chloride impart a greenish colour to a solution of β-naphthol.

Method II.—From primary amines by application of the diazo-reaction, e.g. preparation of phenol from aniline, Exp. 184.

Special tests for phenol, C_6H_5OH.

(i) A few drops of ferric chloride impart a violet colour to its neutral solution.

(ii) Bromine water precipitates 2:4:6-tribromophenol from even very dilute solutions.* (Cf. Exp. 41.)

Method III.—Certain *o-* and *p-dihydric phenols* can be prepared by *reducing the corresponding quinones* (Chap. XXIII).

Experiment 139.—Quinol (hydroquinone), $C_6H_4(OH)_2$ (1:4), from quinone.†

$$C_6H_4\begin{cases} O\ (1) \\ O\ (4) \end{cases} \rightarrow C_6H_4\begin{cases} OH\ (1) \\ OH\ (4). \end{cases}$$

An aqueous solution of quinone (Exp. 230) is saturated with sulphur dioxide gas and the solution allowed to stand for some hours. Should the odour of the gas disappear the saturation is repeated. The resulting solution is extracted with ether, the ether distilled off, and the residue recrystallized from a very little water containing sulphur dioxide, with addition of animal charcoal if necessary. Yield almost theoretical.

It forms colourless plates, m.p. 169°, which decompose when quickly heated, and is soluble in water, alcohol, and ether.

Special Test.—Ferric chloride oxidizes quinol to quinone (detected by its odour).

* For estimation of phenols by standard bromine solution, see *Wilkie*, J. S. C. I. 1911, **30**, 398.

† *Nietzki*, B. 1886, **19**, 1467.

Method IV.—Elimination of carbon dioxide from phenolic carboxylic acids.

$$\underset{\text{Gallic acid}}{(OH)_3{\cdot}C_6H_2{\cdot}CO_2H} \rightarrow \underset{\text{Pyrogallol}}{C_6H_3(OH)_3} + CO_2.$$

Experiment 140.—Pyrogallol, $C_6H_3(OH)_3$ (1:2:3), **from gallic acid.***

A mixture of one part of gallic acid with two parts of powdered pumice is heated in a retort on a sand bath. Through the tubulus of the retort a tube is fixed, through which a current of dry carbon dioxide (from a Kipp's generator) is passed in. The neck of the retort becomes filled with long, glistening needles; if the temperature rises above the melting-point of pyrogallol, the crystals melt and the substance solidifies again in the receiver to a crust. Yield, 40 per cent of theory; m.p. 133°. Pyrogallol is soluble in water, alcohol and ether, and its solutions in alkali readily absorb oxygen.

B. Characteristic Reactions of the Phenols

The solubility of the phenols in water tends to increase, and the solubility in ether to diminish with increase in the number of hydroxy-groups present in the molecule. The readiness with which they are oxidized in alkaline solution also increases with the number of hydroxy-groups.

Colour Reactions of the Phenols.—(i) **With Ferric Chloride.**—Aqueous solutions of phenols yield colorations varying from red to violet with ferric chloride solution. The colorations produced by ferric chloride are more or less characteristic. Monohydric phenols, with the exception of thymol and nitrophenols, give violet or blue colorations, ortho-dihydric phenols green, meta- violet, and trihydric green, violet, or even black. Para-dihydric phenols are oxidized to the corresponding quinones.

(ii) **Liebermann's Reaction.**—Most phenols, when warmed with concentrated sulphuric acid and a little potassium nitrite (or a nitrosamine, Exp. 164), and then diluted with water and made alkaline, yield intense blue, purple, or green colorations.

Experiment 141.—Warm a crystal of phenol with 1 ml. of

* *Liebig*, A. 1857, **101**, 48.

concentrated sulphuric acid and a drop of potassium nitrite solution. Pour into water and add potassium hydroxide solution until alkaline. A blue coloration is produced.

(iii) **Formation of Dyes.**

(*a*) Alkaline solutions of phenols condense with diazonium compounds yielding azo-dyes. (Exp. 192.)

(*b*) With phthalic anhydride most phenols yield phthaleins (Exp. 310), but *m*-dihydric phenols yield fluoresceins (Exp. 311). The last reaction is used as a test for *m*-dihydric phenols such as resorcinol.

The phenols are more distinctly acidic than the alcohols; they dissolve, for example, in solutions of alkali hydroxides yielding *phenoxides* or *phenolates.*

$$C_6H_5OH \rightarrow C_6H_5ONa.$$

The phenoxides derived from simple phenols are decomposed by very weak acids, e.g. by passing a current of carbon dioxide (cf. Acids). The entrance of acidic groups (e.g. nitro-groups) into the molecule strengthens the acidic properties, e.g. the salts of the nitro-phenols (Exp. 117) are not decomposed by carbon dioxide, while picric acid (sym-trinitrophenol, Exp. 118) is a strong acid. A mixture of a phenol and a carboxylic acid may frequently be separated by treatment with sodium carbonate solution, the acid dissolving to form its sodium salt while the phenol is not affected; or the mixture may be dissolved in sodium hydroxide solution and the solution saturated with carbon dioxide, in which case the free phenol is precipitated. The method only applies in cases where the phenol is sparingly soluble in water or where it can be extracted with ether; thus, it is of little use for the separation of the polyhydric phenols from acids.

Experiment 142.—Separate a mixture of benzoic acid and β-naphthol by the above method.

C. Phenolic Ethers and Esters

The hydrogen atoms of the hydroxy-groups of phenols can be replaced by alkyl groups when *phenolic ethers* are obtained, or by acyl groups when *phenolic esters* are formed. For the latter, see Derivatives, Chap. XIX.

Phenolic Ethers. (Cf. Ethers, Chap. X, D.)

The commonest type of phenolic ether is that in which the hydrogen atoms of the hydroxy-groups are replaced by alphyl-groups, e.g. phenetole, $C_6H_5 \cdot OC_2H_5$; resorcinol dimethyl ether, *m*-$C_6H_4(OCH_3)_2$; but diaryl ethers, e.g. $(C_6H_5)_2O$, are also known.

Formation of Alkyl Ethers.

Method I.—By the action of alkyl halides on sodium phenoxides.

$$C_6H_5ONa + C_2H_5I \rightarrow C_6H_5OC_2H_5 + NaI.$$

Experiment 143.—Phenetole, $C_6H_5 \cdot O \cdot C_2H_5$, from phenol.

2·3 g. of sodium in fine shavings are dissolved in 30 ml. of absolute alcohol contained in a flask fitted with a reflux condenser. After the sodium has dissolved and the solution cooled, the theoretical amount of phenol and slight excess of ethyl iodide ($1\frac{1}{4}$ molecule) are added, and the mixture heated on a water bath until the solution is no longer alkaline (about two hours). The alcohol and excess of ethyl iodide are then distilled off on the water bath and the residue treated with water. A layer of phenetole separates on the surface of the aqueous solution. This is extracted with ether, the ethereal solution shaken with dilute sodium hydroxide solution, and then washed with water, dried with calcium chloride, and distilled. The colourless liquid distilling between 169° and 172° is collected separately. B.p. 172°; $D_{4°}^{0°}$, 0·9822.

Method II.—By the action of alkyl sulphates on the metallic phenoxides. As methyl sulphate is a cheap reagent, methyl ethers are invariably prepared by this method.

Experiment 144.—Pyrogallol trimethyl ether (1:2:3-**tri-methoxy-benzene**), $C_6H_3(OCH_3)_3$, **from pyrogallol.***

Caution.—Methyl sulphate is exceedingly poisonous and must always be used in a fume cupboard.

31 ml. of methyl sulphate, $(CH_3)_2SO_4$, are added gradually to a well-shaken solution of 12 g. of pyrogallol in 35 ml. of 40 per cent sodium hydroxide solution. The mixture becomes warm and a dark precipitate is deposited. This is filtered, washed with water, and dissolved in ether in order to remove insoluble impurities. The ether is distilled off from the solution, and the residue crystallized from dilute alcohol, when it is obtained as colourless crystals, m.p. 47°, b.p. 235°. Yield, 12 g., i.e. 75 per cent of theory.

* *Ullmann*, A. 1903, **327**, 116.

D. Removal of Hydroxyl Radicals from Phenols

This is usually accomplished by distilling the phenol with an excess of zinc dust, when the corresponding hydrogen derivative is obtained in the distillate.* Phenol treated in this manner yields benzene, the naphthols yield naphthalene, and the hydroxy-ketone, alizarin, yields anthracene (cf. Exp. 271).

E. Estimation of Hydroxy-Groups in Phenols and Alcohols

Method I.—By preparing the acetyl derivative (Chap. XIX), and determining the amount of acetic acid formed when the acetyl derivative is hydrolysed (Exp. 179).

Method II.—By treating a known weight of the hydroxylic compound with an excess of methyl-magnesium-iodide dissolved in amyl ether or, preferably, phenetole, and measuring the amount of methane evolved.†

$$R{\cdot}OH + CH_3{\cdot}Mg{\cdot}I \rightarrow R{\cdot}OMgI + CH_4$$

$$R''\Big\langle\begin{matrix}OH\\OH\end{matrix} + 2CH_3{\cdot}MgI \rightarrow R''{:}(OMgI)_2 + 2CH_4.$$

Experiment 145.—Determination of the percentage of hydroxy-group in a given compound.

(*a*) **Preparation of a phenetole solution of methyl-magnesium-iodide.** (Cf. Chap. XXIX, A.)

Commercial phenetole is left for some time with metallic sodium, then removed and left over phosphorus pentoxide, and finally distilled (b.p. 169–172°). A crystal of iodine is added to a mixture of 100 g. of the dry phenetole, 6 g. of dry magnesium, and 35·5 g. of methyl iodide in a round-bottomed flask. If the reaction does not begin spontaneously, the mixture is warmed gently and finally heated in a rapidly boiling water bath for one to two hours, using a reflux condenser and protecting from atmospheric moisture. Any excess of methyl iodide is then distilled off on the water bath, and the

* *Baeyer*, A. 1866, **140**, 295.

† *Hibbert* and *Sudborough*, J. C. S. 1904, **85**, 933; *Zerewitinoff*, B. 1907, **40**, 2023.

clear solution decanted into a well-stoppered bottle and kept in a desiccator. *N.B.*—The solution is gradually acted upon by moisture, carbon dioxide, and oxygen, and should be protected from these as far as possible.

(*b*) **Estimation of hydroxy-groups.**—0·1 to 0·25 g. of the perfectly dry substance is introduced into a stout glass flask or bottle of 200 ml. capacity, fitted with a rubber bung which carries a delivery tube, which can be connected by stout rubber tubing with the measuring tube of a Hempel gas burette filled with dry mercury * (fig. 83). Dry phenetole (10–20 ml.) is added, or if the hydroxy-compound is insoluble in ether, *dry* pyridine † may be used, and the substance dissolved by heating gently. About 15 ml. of the phenetole solution of methyl-magnesium-iodide are placed in a *separate* tube which is introduced into the flask or bottle. The latter is then fixed in a constant-temperature bath, the rubber bung introduced and connected with the measuring tube of the gas burette, which contains dry mercury. After the bottle has attained the temperature of the bath, the temperature and position of the mercury in the measuring tube is noted. The two solutions are then mixed by tilting the bottle, and the mixture is thoroughly shaken. For this purpose it may be

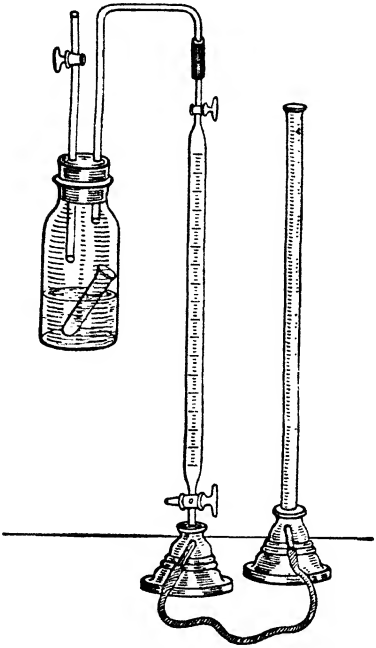


Fig. 83

* It is an advantage to have a glass T-piece connected by rubber to the two glass tubes of the Hempel burette, and to attach a glass stopcock to the remaining end of this T, so that mercury can be run out of the apparatus through the cock.

† Pyridine is dehydrated by heating with barium oxide, distilling, and preserving over a further quantity of the oxide.

withdrawn from the bath. When no more gas is evolved the bottle is replaced in the bath, and when the volume of gas in the burette is constant (after five to seven minutes) the volume, temperature, and pressure are observed.* From these data the weight of methane evolved can be calculated, and since 16 g. of methane are equivalent to 17 g. of hydroxyl, the weight and percentage of hydroxyl in the compound can be determined.

If the molecular weight of the substance is known, the number of hydroxy-groups present in the molecule can be readily calculated.

A modification of the above procedure whereby dry ethyl ether (cf. Exp. 29) is used as solvent can be adopted if the appropriate corrections for the vapour pressure of the solvent are made.† This simplified method is only applicable to relatively non-volatile compounds with functional groups reacting completely at room temperature.

The reagent is prepared by reaction of methyl iodide (35 g.) with excess of magnesium (8 g.) in dry ether (200 ml.) and decanting the liquid into a 300 ml. brown-glass stoppered bottle from which air has been displaced by nitrogen. After some hours the reagent is redecanted and the volume made up to 250 ml.

Determinations are carried out in an ordinary 50 ml. nitrometer filled with dry mercury and fitted with a rubber stopper carrying a small graduated dropping funnel (fig. 84).

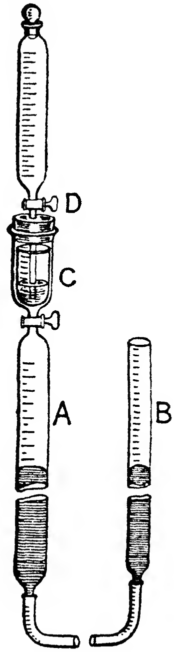


Fig. 84

About 0·5 ml. of dry ether is placed above the mercury in A. The sample (50–200 mg.) is weighed into a wide specimen tube which is then placed at C, 2 ml. of dry ether are added and the stopper and funnel replaced. The mercury level in A is adjusted to the zero mark, tap D is closed and the apparatus tested for leaks. 3 ml. of reagent are then placed in the funnel, B is lowered and about 2 ml. of reagent are allowed to enter

* If pyridine be used as solvent, the volume falls to a minimum, but then tends to increase. In this case the minimum reading must be taken.

† *Braude* and *Stern*, J. C. S. 1946, 404.

drop by drop, by manipulating tap D until no further action takes place. The level in B is then adjusted slightly above that in A and the apparatus allowed to rest for 5 minutes. B is then levelled with A and the volume read in A. A blank experiment using the same volume of reagent should be carried out.

The reading in A − (vol. of reagent run in) − (blank reading, if any) = volume of methane evolved at a pressure equal to atmospheric pressure (p) − vapour pressure of diethyl ether (p') at the temperature of the experiment. The theoretical volume of methane per gram atomic weight of "active" hydrogen is given by

$$v = \frac{\text{Wt.}}{\text{Mol. Wt.}} \times 22{,}400 \times \frac{p}{p - p'} \times \frac{\text{T}}{273} = a \times \frac{\text{Wt. (mg.)}}{\text{Mol. Wt.}}.$$

Conversion factors a for a range of temperatures and pressures are given in Table XXII (p. 438).

F. Hydrolysis of Methoxy- and Ethoxy-Derivatives

The alkyl-oxy-groups may be removed from a compound by:

Method I.—Heating the substance with fairly concentrated hydriodic acid (cf. Estimation of Methoxy-groups, Chap. XVII, G).

Method II.—Heating the substance with anhydrous aluminium chloride.*

Experiment 146.—Catechol, o-$C_6H_4(OH)_2$, from guaiacol, $OH{\cdot}C_6H_4{\cdot}OCH_3$.

12 g. of finely powdered and freshly prepared aluminium chloride (Chap. XXXVIII) are added gradually to 15 g. of guaiacol in an Erlenmeyer flask, surrounded by ice. The mixture is well shaken during the addition, and should be well cooled, so that the reaction does not begin until after the whole of the chloride has been added. It is then removed from the ice, again well shaken, and then heated for two hours at 210–220°, using a reflux air condenser. When cold, the solid mass is removed, broken up, and added to dilute hydro-

* *Hartmann* and *Gattermann*, B. 1892, **25**, 3532.

chloric acid and warmed. The unaltered guaiacol is removed by filtration, the filtrate saturated with common salt, and extracted three times with ether. Yield, 11–12 g. of crude catechol, i.e. 70 per cent of theory. It may be purified by distillation or by crystallization from toluene, and then forms colourless crystals, m.p. 104°; b.p. 245°.

G. Estimation of Methoxy-Groups

This is generally accomplished by Zeisel's method.* The ether is heated with hydriodic acid of constant boiling-point, and the methyl iodide thus formed is led into an alcoholic solution of silver nitrate, and the precipitated silver iodide estimated in the usual manner.

$$X{\cdot}OCH_3 + HI \rightarrow X{\cdot}OH + CH_3I$$
$$CH_3I + AgNO_3 + H_2O \rightarrow AgI + CH_3OH + HNO_3.$$

The method has been simplified by Hewitt and Moore,† and further by Perkin,‡ whose apparatus is shown in fig. 85.

Experiment 147.—Determination of the percentage of methoxyl in a compound by Perkin's method.

A distilling flask with a very long neck (20–25 cm.) is fitted with a tube leading into the bulb, through which a stream of carbon dioxide is passed from a Kipp's generator. The side tube of the distilling flask is attached directly to a pair of absorption flasks arranged as in fig. 85. (Note carefully the position of the siphon tube connecting the two flasks.)

15 ml. of concentrated hydriodic acid (previously purified by distilling over a little red phosphorus; the portion of constant boiling-point, 126° at 760 mm. pressure, is taken) are placed in the distilling flask, and 0·3–0·35 g. of the substance weighed in a small tube added. The stopper carrying the carbon dioxide leading tube is then fixed into the neck of the flask, and the absorption flasks charged, one with 20 ml., the other with 15 ml. of alcoholic silver nitrate solution. The distilling flask is then fixed in a bath of glycerol, which is heated to 130–140°, while a constant current of carbon dioxide is passed through at the rate of three or four bubbles in two seconds. After a time the solution in the first flask becomes

* *Zeisel*, M. 1885, **6**, 989; 1886, **7**, 406.
† J. C. S. 1902, **81**, 318.
‡ J. C. S. 1903, **83**, 1367.

turbid, but the liquid in the second flask is scarcely affected. The temperature of the glycerol bath is then raised gradually until it causes the hydriodic acid to boil gently, but not so vigorously as to cause distillation of the acid into the side tube of the flask. The operation is often completed in three-quarters of an hour; generally the heating is continued for an hour. The flasks are then disconnected, and a V-tube con-

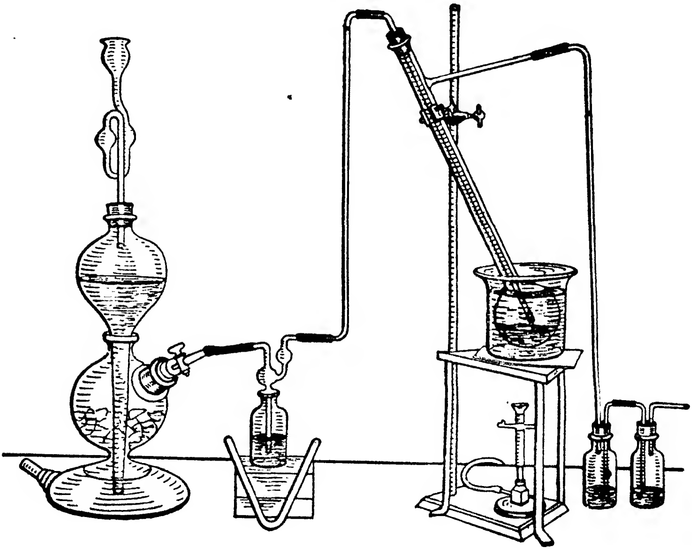


Fig. 85

taining a few ml. of silver nitrate solution substituted. The heating is continued for about twenty minutes, and if no appreciable amount of silver halide forms during that time the operation may be considered complete; otherwise the latter operation is repeated. The precipitate of silver iodide is treated with water, the alcohol removed by evaporation, and after treatment with dilute nitric acid the silver iodide is collected and weighed in the usual manner.

Ethoxy-determinations may be carried out with the same apparatus and in a similar manner, but the results obtained are generally somewhat low; probably a small amount of the ethyl iodide is reduced by the hydriodic acid.

Hewitt and *Jones* * suggest the following modifications of Perkin's method: (1) the long neck of the flask is replaced by a 4 pear rectifying column; (2) the use of *pure* pyridine contained in two test tubes to absorb the methyl iodide. At the end of the experiment the contents of the test tubes are diluted with water, acidified with nitric acid, and the iodide ion estimated by *Volhard's method.*

H. Microanalytical Estimation of Methoxy- and Ethoxy-Groups †

The apparatus is shown in fig. 86. It is first washed, rinsed with distilled water, and the decomposition flask thoroughly dried by drawing a current of clean, warm air through it. The receiver R (made from a test tube widened in the middle and drawn down at the closed end to a diameter of 7 to 8 mm. over a length of 50 mm.) is washed with chromic acid mixture and with distilled water. The washer W is charged with a mixture of three or four drops each of 5 per cent sodium thiosulphate solution and 5 per cent cadmium sulphate solution, introduced from a pipette while holding the apparatus nearly horizontal. This wash liquid prevents hydrogen iodide from being carried over into the receiver. The opening at O is then closed with a cork moistened with distilled water. The receiver, rinsed with alcohol, and with the narrow portion filled with a 4 per cent solution of silver nitrate in alcohol, is now placed in position. 1·5 ml. of pure hydriodic acid (sp. gr. 1·70), 2 drops of acetic anhydride, and a few crystals of phenol are introduced into the boiling flask through the side tube, together with 3–5 mg. of the material to be analysed, weighed into a small tinfoil cup weighing not more than 20 mg. The mixture of acetic anhydride and phenol forms a suitable solvent; the tinfoil causes separation of stannous iodide, which prevents bumping. To diminish risk of loss through the side tube of the boiling flask a loosely fitting glass rod is suspended in it, after which it is connected to a Kipp's carbon dioxide generator, the gas rate being adjusted so that bubbles rise separately and very slowly through the silver nitrate solution. The contents of the boiling flask are now warmed by

* J. C. S. 1919, 193.

† *A. Friedrich*, Hoppe-Seylers Ztsch. 1927, **163**, 141; *Pregl*, l.c., 181.

means of a micro-burner and gently boiled for 20 minutes. The burner is then removed and the delivery tube raised so that its end is above the level of the silver nitrate solution. The cork is taken out of the upper end, and the delivery tube washed inside and out with distilled water and alcohol alternately till free from silver iodide particles. 5 drops of concentrated

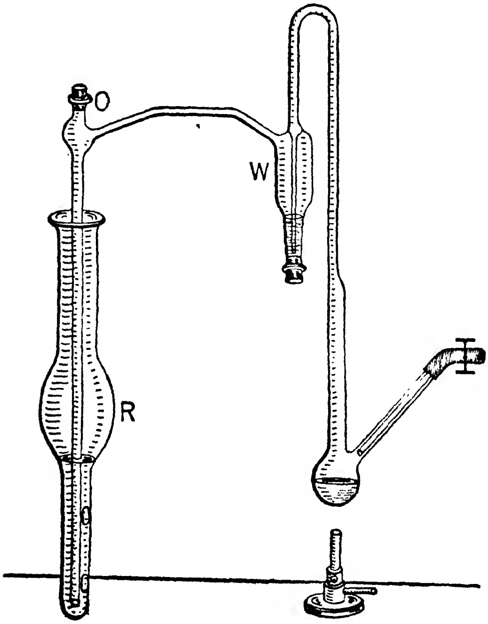


Fig. 86

nitric acid are then added to the contents of the receiver, which is placed on a water bath until boiling begins. The silver iodide is then siphoned into a filter tube as described for the halogen determination (Chap. VI, C).

Methyl groups attached to nitrogen.—The apparatus is modified* so that the higher temperature necessary for the decomposition of the methylimino-group may be attained. The boiling flask is immersed in a bath of powdered copper oxide heated to about 250° C. The hydriodic acid which distils is

* *Friedrich*, loc. cit.; *Pregl*, loc. cit.

condensed in a receiver before the vapour passes into the washer, and from this receiver the acid may be sucked back into the boiling flask without disturbing the contents of the washer, to enable a second distillation to be carried out. The boiling flask contains the materials given above, with the addition of ammonium iodide (10 to 20 times the quantity of substance taken for analysis). A longer time (an hour or more) is required for the liberation of the methyl groups, and one and sometimes two redistillations are necessary.

XVIII. AMINES AND QUATERNARY AMMONIUM COMPOUNDS

(S.B Chaps. IV D; XXI)

The amines are compounds derived from ammonia by the replacement of the hydrogen atoms of the latter by alkyl radicals. Like ammonia, they possess distinctly basic properties, and combine with acids yielding crystalline salts. They are classified as *primary*, *secondary*, *tertiary*, or *quaternary* bases, according as they contain one, two, three, or four monovalent alkyl radicals attached to the nitrogen atom. The first three groups are derived from ammonia and the last from the ammonium hydroxide. Characteristic of the primary amines is the *amino*-group, $\cdot NH_2$, e.g. methyl-amine, $CH_3\cdot NH_2$; of secondary amines the *imino*-group, :NH, e.g. methylaniline, $C_6H_5\cdot NH\cdot CH_3$. Tertiary amines have the N radical attached to three alkyl groups, e.g. dimethylaniline, $C_6H_5\cdot N(CH_3)_2$; the quaternary compounds contain four alkyl groups, e.g. tetramethyl-ammonium iodide, $N(CH_3)_4I$.

A. Primary Amines: Modes of Formation

Method I.—A general method applicable for both alphyl- and aryl-amines is from acid amides or imides (Chap. XIV, B and C) by Hofmann's reaction.* An acid amide is converted by bromine, in the presence of alkali, into a bromamide.

$$R\cdot C\overset{\displaystyle /\!\!/ O}{}\!-NH_2 + Br_2 = R\cdot C\overset{\displaystyle /\!\!/ O}{}\!-NH\cdot Br + HBr.$$

* *Hofmann*, B. 1882, **15**, 407, 752; 1884, **17**, 1407, 1920; 1885, **18**, 2734.

The bromamide by further action of alkali loses HBr, and probably yields an iso-cyanate (alkyl carbimide), which is then hydrolysed by an excess of alkali to an amine and a carbonate.

$$R{\cdot}CO{\cdot}NHBr \rightarrow R{\cdot}N{:}C{:}O + HBr$$
$$R{\cdot}N{:}C{:}O + H_2O \rightarrow R{\cdot}NH_2 + CO_2.$$

The amine can be obtained by distilling the product, or by separation as a salt.

Experiment 148.—Methylamine hydrochloride, $CH_3{\cdot}NH_2$, HCl, **from acetamide.**

20 g. of dry acetamide (1 mol) (Exp. 103) are mixed with 54 g. of bromine (1 mol) in a 500 ml. flask, and a solution of 20 g. of potassium hydroxide (1 mol) in 200 ml. of water is added gradually, the flask being cooled during the addition by immersion in cold water. The reddish-brown liquid changes gradually to a yellow colour. The mixture, which now contains acetbromamide, is dropped slowly from a tap funnel into a concentrated solution of potassium hydroxide (60 g. in 100 ml.), contained in a large distilling flask (500 ml. capacity). During this process heat is generated, and the temperature of the mixture must on no account be allowed to rise above 75°. The liquid is then kept at a temperature of 65–70°, until the yellow colour disappears (about half an hour). The side tube of the distilling flask is attached to a condenser which terminates in an adapter fitted into a gas absorption tube. The liquid is distilled over a wire gauze, and the volatile ammonia and methylamine absorbed in 100 ml. of dilute hydrochloric acid. When the drops of distillate are no longer alkaline, the hydrochloride solution is evaporated to dryness on a water bath, and the colourless crystalline residue of methylamine hydrochloride and ammonium chloride extracted several times with hot *absolute* alcohol, in which ammonium chloride is practically insoluble. The methylamine hydrochloride crystallizes from the alcoholic solution; the crystals are removed, washed with a little alcohol, and dried in a desiccator.

It consists of colourless deliquescent plates, m.p. 200°, and sublimes above 220°, with slight decomposition.

Acid imides when treated in a similar manner yield amino-acids.

Experiment 149.—Anthranilic acid, $C_6H_4\langle{}^{CO_2H\ (1)}_{NH_2\ \ (2)}$, from phthalimide.*

$$C_6H_4\langle{}^{CO}_{CO}\rangle NH \rightarrow C_6H_4\langle{}^{CO_2H}_{NH_2}$$

28 g. of potassium hydroxide (5 mols) are dissolved in 280 g. of water, and 16 g. of bromine (1 mol) added gradually while the solution is cooled and well stirred. (The mixture contains 1 mol of potassium hypobromite and 3 mols of potassium hydroxide.) To the well-cooled solution 15 g. of phthalimide (1 mol) (Exp. 108) are added gradually, care being taken that the mixture is cooled and well shaken. Then 12 g. of potassium hydroxide (2 mols) in 120 ml. of water are added, and the mixture warmed to 80°. The solution is acidified with acetic acid and excess of a strong solution of cupric acetate (20 g.) added. After shaking, it is allowed to stand for some time, when cupric anthranilate separates as a pale-green precipitate.† This is filtered off on a Buchner funnel, washed with cold water, and then suspended in a small amount of warm water and decomposed by completely saturating with sulphuretted hydrogen. (Allow to stand for a short time after passing the gas to ensure the thorough decomposition of the salt.) The cupric sulphide is filtered off, washed with a little water, and the aqueous filtrate and washings evaporated to a small bulk on a water bath and allowed to stand. Anthranilic acid separates as colourless crystals, m.p. 145°; it is soluble in water, and the aqueous solution possesses a sweet taste. Yield, 85 per cent of theory.

The substance possesses both acidic and basic properties.

Method II.—By the reduction of nitro-compounds (Chap. XV), usually in acid solution. This method is applicable for the preparation of both alphyl and arylamines, but is generally used in the aromatic series only.

For the reduction of each nitro-group six atoms of nascent hydrogen are necessary, and the reaction may be expressed as follows:

$$X{\cdot}NO_2 + 6H = X{\cdot}NH_2 + 2H_2O.$$

The amine produced combines with excess of acid to form

* *Hoogewerff* and *van Dorp*, Rec. 1891, **10**, 6.
† Characteristic of amino-acids.

a salt, e.g. $X \cdot NH_2 \cdot HCl$, from which the amine is obtained by the addition of an excess of caustic alkali.

Almost any combination of metal and acid which gives rise to nascent hydrogen may be used, but in the laboratory a mixture of tin and hydrochloric acid is usually employed. In this case the metal is first converted into stannous, and then into stannic chloride. The complete reaction may be represented thus:

$$2R \cdot NO_2 + 3Sn + 14HCl = 2(R \cdot NH_2HCl) + 3SnCl_4 + 4H_2O.$$

The hydrochloride of the amine combines with the stannic chloride, forming a *stannichloride*, $(RNH_2,HCl)_2SnCl_4$.

Various methods are adopted in order to obtain the free amine from the acid mixture. If it is volatile with steam, the reaction product is treated with excess of an alkali hydroxide, which, in addition to liberating the free amine, redissolves the stannic hydroxide at first precipitated with the formation of stannates, and the amine is then distilled over with steam. Solid amines are obtained directly by filtering off from the alkaline fluid. Direct extraction of the alkaline tin solution with ether is not advisable, owing to the formation of difficultly separable emulsions of the alkaline solution with ether. For the separation of non-volatile amines it is therefore necessary to precipitate the tin from the diluted acid solution by means of hydrogen sulphide. The stannous or stannic sulphide is separated by filtration, the amine hydrochloride subsequently decomposed with alkali, and the free amine extracted with ether.

Experiment 150.—Reduction of nitrobenzene to aniline (phenylamine), $C_5H_6 \cdot NH_2$.

40 g. of nitrobenzene (Exp. 113) and 75 g. of granulated tin are placed in a round-bottomed flask of 2 litres capacity fitted with a long air-condenser, and 200 ml. of concentrated hydrochloric acid (sp. gr. 1·16) are added *gradually* through the condenser tube in quantities of about 10 ml. at a time. The mixture is shaken well after each addition; it soon becomes warm, but active ebullition must be prevented by cooling the flask when necessary under the tap, otherwise some nitrobenzene and aniline are lost. Towards the end the reaction moderates, and the remainder of the acid may then be added more quickly. To ensure complete reduction, the flask is heated on a water bath until no odour of nitrobenzene can be

detected, a little more tin being added if necessary. To obtain the amine from the stannichloride, $(C_6H_5{\cdot}NH_2,\ HCl)_2SnCl_4$, the contents of the flask are diluted with water (100 ml.), and then made strongly alkaline by the gradual addition of sodium hydroxide solution (150 g. in 200 ml. of water). The addition is carried out slowly so as to avoid active ebullition and consequent loss of amine. The alkali is added until the stannic hydroxide at first precipitated is completely redissolved, and the mixture shows a strongly alkaline reaction. The aniline separates out during this process as a dark oil, and is removed by distillation with steam (fig. 10), the operation being continued until the liquid which passes over is no longer milky in appearance but perfectly clear. The distillate, which consists of two layers—an oily layer of aniline, together with an aqueous solution of the base—is saturated with common salt (about 25–30 g. for each 100 ml. of distillate) and extracted with ether. The ethereal solution is separated and dehydrated by allowing to stand for some time with solid potassium hydroxide. The clear liquid is decanted into a distilling flask, the potash and the vessel being washed with a little ether, the ether removed, and the aniline distilled, an air-condenser being used (fig. 82). Yield, 27 g., i.e. about 90 per cent of theory.

It is a colourless, oily, strongly refracting liquid, which becomes yellow on standing, and possesses a peculiar odour. B.p. 182°; D^{15}, 1·0265. It is only sparingly soluble in water.

Special Tests for Aniline (for General Tests, cf. pp. 226, 227).

(i) Dilute solutions of aniline or its salts give a violet coloration with a solution of bleaching powder.

(ii) Bromine water gives a precipitate of tribromaniline with even very dilute solutions of aniline or its salts (cf. Exp. 41).

(iii) The addition of potassium dichromate solution to a few drops of aniline dissolved in dilute sulphuric acid produces a precipitate—green, blue, or black (aniline black), according to the concentration.

Poly-nitro-compounds are completely reduced by the above process to the corresponding poly-amino-compounds, e.g. the complete reduction of *m*-dinitrobenzene yields *m*-phenylenediamine.

$$C_6H_4(NO_2)_2(1{:}3) \rightarrow C_6H_4(NH_2)_2(1{:}3).$$

Experiment 151.—*m*-Phenylenediamine from *m*-dinitrobenzene.

25 g. of *m*-dinitrobenzene (Exp. 114) are treated with 100 g. of granulated tin, and 200 ml. of concentrated hydrochloric acid, as described in the last experiment. The reduction is completed by heating the product on the water bath for an hour. On cooling, crystals of the *stannochloride*, $C_6H_4(NH_2)_2$, 2HCl, $2SnCl_2$, separate as slender needles; these are removed with the aid of the pump and dissolved in warm water.

The solution is diluted with water, and a current of sulphuretted hydrogen led through until the tin is completely precipitated. The sulphide is removed, the filtrate made alkaline by the addition of sodium hydroxide solution, and extracted several times with ether. After drying with solid potassium hydroxide the solution is fractionated from a small (50 ml.) flask, the solution being added to the flask in small portions. The product crystallizes from the concentrated ethereal solution and may be recovered by filtration; or it may be distilled with the aid of an air condenser after complete removal of the ether. M.p. 63°, b.p. 282–284°. The dihydrochloride may be obtained by passing dry HCl into the dried ethereal solution obtained above.

If it is desired to reduce but one or two out of several nitro-groups, special methods are necessary. An alcoholic solution of ammonium sulphide is the reagent generally used, as this substance reduces the nitro-groups in stages, and the reaction can be stopped at the desired point.

Experiment 152.—*m*-Nitraniline, $C_6H_4\begin{cases} NH_2 \ (1) \\ NO_2 \ (3) \end{cases}$, **from *m*-dinitrobenzene.***

$$C_6H_4(NO_2)_2 + 3H_2S \rightarrow NH_2{\cdot}C_6H_4{\cdot}NO_2 + 2H_2O + 3S.$$

20 g. of *m*-dinitrobenzene (Exp. 114) are dissolved in 60 g. of 90 per cent alcohol, and 10 g. of strong ammonia solution (D, 0·880) added. The flask and its contents are weighed; then hydrogen sulphide is led in, until the solution is saturated. The flask is allowed to stand in a warm place until the smell of sulphuretted hydrogen has disappeared; it is then cooled and again saturated with hydrogen sulphide, the process being repeated until the theoretical increase of weight of the contents of the flask (12 g.) is attained.

* *Beilstein* and *Kurbatow*, A. 1875, **176**, 44. For the mechanism of the reaction, cf. *Cohen* and *M'Candlish*, J. C. S. 1905, **87**, 1257.

The *m*-nitraniline is precipitated by the addition of water to the alcoholic solution. It is purified from any unchanged dinitrobenzene by solution in dilute hydrochloric acid, and precipitation with ammonia. Yield, 70–80 per cent of theory. It crystallizes from hot water in long straw-coloured needles, m.p. 114°; it dissolves in most organic solvents, and forms salts with mineral acids.

Method III.—The monoalkyl derivatives of phthalimide, obtained by the action of alkyl halides on potassium phthalimide (Exp. 109), when hydrolysed with mineral acid yield phthalic acid and primary amines quite free from secondary and tertiary amines.

$$C_6H_4\left\langle{CO \atop CO}\right\rangle NK \underset{RBr}{\rightarrow} C_6H_4\left\langle{CO \atop CO}\right\rangle NR \underset{2H_2O}{\rightarrow} C_6H_4\left\langle{COOH \atop COOH}\right. + R{\cdot}NH_2$$

The method is one frequently used for the preparation of primary amines difficult to obtain by other methods (Gabriel, B., 1887–1902), particularly amines containing halogen.

Experiment 153.—**β-Bromoethylamine hydrobromide.**

(*a*) Potassium phthalimide (50 g.) and ethylene dibromide (60 g.) are heated in a reflux apparatus in an oil bath at 150°. When no more dibromide condenses in the tube, the contents of the flask are thoroughly mixed and again heated until they form a brownish-yellow syrup. 180 ml. of hot alcohol are added and the mixture heated in the same apparatus until the insoluble part forms a yellowish powder free from lumps. This consists of potassium bromide and the compound

$$C_6H_4\left\langle{CO \atop CO}\right\rangle N{\cdot}CH_2{\cdot}CH_2{\cdot}N\left\langle{CO \atop CO}\right\rangle C_6H_4.$$

The solution is filtered hot and the filtrate evaporated to remove solvent. The crude bromoethylphthalimide,

$$C_6H_4\left\langle{CO \atop CO}\right\rangle N{\cdot}CH_2{\cdot}CH_2Br,$$

can be crystallized from hot carbon disulphide and forms colourless needles (m.p. 82–83°). Yield, 30 g.

(*b*) 20 g. of the bromoethylphthalimide are heated with 55 ml. hydrobromic acid (sp. gr. 1·49) in sealed tubes at 180–200° during two hours. The product is washed out with water, the

solid phthalic acid removed by filtration, and the filtrate on evaporation yields a crystalline mass of β-bromoethylamine hydrobromide, $CH_2Br \cdot CH_2 \cdot NH_2$, HBr, which crystallizes from hot alcohol as needles. Yield of crude product, 15 g.

Method IV.—A method of obtaining amino-derivatives in the anthraquinone series is by the indirect replacement of halogens in the 1-position by amino-groups. The halogen compound is condensed with *p*-toluene sulphonamide,

$$R \cdot Cl + NH_2 \cdot SO_2 \cdot C_6H_4 \cdot CH_3 \rightarrow R \cdot NHSO_2 \cdot C_6H_4 \cdot CH_3 + HCl,$$

and the product hydrolysed with concentrated sulphuric acid,

$$R \cdot NH \cdot SO_2 \cdot C_6H_4 \cdot CH_3 + H \cdot OH \rightarrow R \cdot NH_2 + OH \cdot SO_2 \cdot C_6H_4 \cdot CH_3.$$

Experiment 154.—1-Aminoanthraquinone from 1-chloro-anthraquinone.*

(*a*) 1-*p*-Toluenesulphonamide-anthraquinone from 1-chloro-anthraquinone.*

$$C_{14}H_7O_2Cl + NH_2 \cdot SO_2 \cdot C_6H_4 \cdot CH_3 \rightarrow C_{14}H_7O_2 \cdot NH \cdot SO_2 \cdot C_6H_4 \cdot CH_3 + HCl.$$

5 g. 1-chloroanthraquinone (Exp. 47), 5 g. *p*-toluenesulphonamide (Exp. 136), 4 g. anhydrous potassium carbonate, 0·2 g. copper acetate, 0·1 g. copper bronze, and 50 ml. nitrobenzene are heated in an oil bath at 180–200° under a reflux condenser for 3 hours. The mixture is then allowed to cool to 100° and the nitrobenzene removed by steam distillation. The residue is filtered, extracted with 200 ml. of glacial acetic acid and crystallized. The product consists of lustrous brassy-yellow crystals; yield, 6·5 g.; m.p. 228°.

(*b*) 1-Aminoanthraquinone, $C_{14}H_7O_2 \cdot NH_2$. The sulphonamide derivative is heated with 10 times its weight of concentrated sulphuric acid on a water bath. The colour of the solution changes gradually from orange, through yellow, to red. It is then poured into excess of cold water and the red precipitate filtered off and dried by suction. M.p. 243°. Yield theoretical.

The sulphonic acid group in 2-derivatives of anthraquinone can be directly replaced by the amino-group by heating with concentrated ammonia solution under pressure. Thus silver salt (Exp. 129) when heated in this way yields 2-aminoanthraquinone.

* *Ullmann* and *Fodder*, A. 1917, **380**, 319.

B. Secondary Amines

1. By the Hydrolysis of a Dialkylated *p*-Nitroso-aniline.

$$NO\cdot C_6H_4\cdot NMe_2 + H\cdot OH \rightarrow NO\cdot C_6H_4\cdot OH + NHMe_2.$$

Experiment 155.—Dimethylamine from *p*-nitroso-dimethylaniline.

A solution of 20 g. of *p*-nitroso-dimethylaniline hydrochloride (Exp. 165) in 100 ml. of water is added in small portions to a solution of 30 g. potassium hydroxide in 500 ml. water, and heated in a litre distillation flask attached to a condenser with an adapter dipping into 75 ml. of 2 N. hydrochloric acid. The addition of hydrochloride is regulated so that a further addition is made as soon as the oily drops produced by the former addition have ceased to pass over. When the distillation is completed the contents of the receiver should still be acid and on evaporation to dryness yield the solid dimethylamine hydrochloride which can be crystallized from absolute alcohol. Yield, 75 per cent of theory.

The other product, *p*-nitrosophenol (quinonemonoxime) can be obtained by acidifying the contents of the flask and extracting with ether. M.p. 130° with decomposition.

2. Conversion of a Primary Arylamine into a Secondary Alphyl-arylamine.

Experiment 156.—Preparation of methylaniline, $C_6H_5NH\cdot CH_3$, from aniline.*

$$C_6H_5N\Big\langle\begin{matrix}H\\CO\cdot CH_3\end{matrix} \rightarrow C_6H_5N\Big\langle\begin{matrix}Na\\CO\cdot CH_3\end{matrix}$$

$$C_6H_5N\Big\langle\begin{matrix}Na + I\cdot CH_3\\CO\cdot CH_3\end{matrix} \rightarrow C_6H_5N\Big\langle\begin{matrix}CH_3\\CO\cdot CH_3\end{matrix} + NaI$$

$$C_6H_5\cdot N\Big\langle\begin{matrix}CH_3\\CO\cdot CH_3\end{matrix} + KOH \rightarrow C_6H_5N\Big\langle\begin{matrix}CH_3\\H\end{matrix} + CH_3CO_2K.$$

20 g. of acetanilide (for preparation from aniline, see Exp. 166), 5 g. of sodium wire, and 100 g. of pure xylene (dried over sodium) are heated in a flask fitted with a reflux condenser for 2–3 hours in an oil bath at 130°. After cooling,

* *Hepp*, B. 1877, 10, 328.

rather more than the theoretical weight of methyl iodide is added, and the mixture digested for a short time, until no more methyl iodide condenses in the condenser tube. The xylene is then distilled off.

The methylacetanilide is decomposed by boiling with concentrated alcoholic potash solution for about 24 hours in a reflux apparatus. The alcohol is distilled off, and the residue neutralized by addition of hydrochloric acid. The residual xylene is then distilled off with steam, the solution made alkaline and the methylaniline distilled over with steam. It is taken up with ether, dried with fused sodium sulphate or potassium hydroxide, and fractionated. It is a yellowish oil, b.p. 192°; $D_{4°}^{15°}$, 0·976. Yield almost theoretical.

A simple method * for preparing monoalkylated anilines consists in heating a large excess of aniline with the alkyl bromide. The mixture of aniline and monoalkyl derivative is treated with zinc chloride solution, when an insoluble compound of aniline is formed and the monoalkyl compound remains as an oil.

Experiment 157.—*n*-Propylaniline, $C_6H_5{\cdot}NH{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3$.

A mixture of aniline (77 g.) and *n*-propyl bromide (41 g.) is heated in a reflux apparatus on the water bath for 6 hours and the product treated with alkali. The oily mixture of amines is treated with a solution of zinc chloride (50 g.) in water (50 g.). The mixture, when cooled and stirred, yields a thick paste consisting of the solid additive compound of aniline with zinc chloride and the oily *n*-propylaniline. After 12 hours the paste is rapidly drained on a large Buchner funnel, washed with cold water, well pressed, and extracted with boiling light petroleum. The combined extracts are washed with water, dilute ammonia, dried over potassium carbonate and distilled. 31 g. of oily *n*-propylaniline boiling at 218–222° are obtained, and to separate traces of tertiary amine it is converted into its acetyl derivative by distilling with an equal weight of acetic anhydride. This distils at 240–265° and after crystallizing from light petroleum melts at 48–49°. On hydrolysis with alkali it yields the pure base; b.p. 222°.

Experiment 158.—Ethyl-α-naphthylamine.

$$C_{10}H_7NH_2 + C_2H_5I \rightarrow C_{10}H_7{\cdot}NH{\cdot}C_2H_5 + HI.$$

A mixture of 20 g. of α-napththylamine, 33 g. of ethyl

* *Hickinbottom*, J. C. S. 1930, 993.

iodide, and excess of sodium carbonate (40 g.) in 500 ml. of water is heated in a reflux apparatus on a water bath for 3 hours. The ethyl-α-naphthylamine is extracted with ether, dried with potassium hydroxide, the ether and excess of ethyl iodide removed, and the residue fractionated, preferably under diminished pressure. Yield almost theoretical. It is a pale-yellow oil, b.p. 301–302° at 760 mm., 200° at 75 mm.

3. **Conversion of a Primary Arylamine into a Secondary Arylamine.**

Experiment 159.—Diphenylamine, $(C_6H_5)_2NH$, from aniline.*

$$C_6H_5\cdot NH\cdot CO\cdot CH_3 + C_6H_5Br \rightarrow (C_6H_5)_2N\cdot CO\cdot CH_3 + HBr$$
$$(C_6H_5)_2N\cdot CO\cdot CH_3 + H_2O \rightarrow (C_6H_5)_2NH + CH_3\cdot CO_2H.$$

10 g. of acetanilide (Exp. 166), 5 g. of dry potassium carbonate, 20 g. of phenyl bromide, a little cuprous iodide, and 25 g. nitrobenzene are boiled for 15 hours in a reflux apparatus. The product, a dark-brown liquid, is distilled with steam until no more nitrobenzene passes over. The residue in the distillation flask, consisting of the acetyl derivative of diphenylamine, is a thick brown oil. It is taken up with ether, the solution filtered, dried with calcium chloride, and the ether removed. The residue is crystallized from alcohol, and is obtained as yellow plates, m.p. 102°.

The crystals are dissolved in 30 ml. of alcohol and decomposed by boiling with 30 ml. of concentrated hydrochloric acid for 2–3 hours. The product is distilled with steam, a yellow oil passing over which solidifies in the condenser. It crystallizes from alcohol in yellow crystalline plates, m.p. 54°, b.p. 310°. Yield, 7·5 g., i.e. 60 per cent of theory.

Polynitro-derivatives of diarylamines are readily formed by condensing an arylamine with 2:4-dinitrochlorobenzene or with picryl chloride (cf. Chap. XIX, F).

C. Tertiary Amines

Conversion of an Arylamine into a Tertiary Alphylarylamine.

Primary arylamines which contain an ortho-substituent can be readily transformed into tertiary amines by heating with methyl iodide and sodium carbonate solution (Noelting's method).†

* *Goldberg* and *Sissoeff*, B. 1907, **40**, 4543.
† *Noelting*, B. 1891, **24**, 563.

Experiment 160.—Dimethyl-*o*-toluidine, $CH_3{\cdot}C_6H_4{\cdot}N(CH_3)_2$ (1:2), **from** ***o*-toluidine,** $CH_3{\cdot}C_6H_4{\cdot}NH_2$ (1:2).

$$C_6H_4\begin{cases}CH_3\ (1)\\NH_2\ (2)\end{cases} + 2CH_3I + Na_2CO_3 \rightarrow C_6H_4\begin{cases}CH_3\quad(2)\\N(CH_3)_2\ (1)\end{cases} + 2NaI + H_2O + CO_2.$$

A mixture of 15 g. of *o*-toluidine with a little more than the theoretical weight of methyl iodide, and slight excess of sodium carbonate, dissolved in 250 ml. of water, is heated in a reflux apparatus on a water bath, until methyl iodide no longer condenses in the condenser tube (about 2 hours). The liquid is made alkaline with sodium hydroxide, and the amine extracted with ether; the ethereal solution is dried with solid caustic potash and distilled, when the amine is obtained as a pale-yellow liquid, b.p. 183°. Yield, 80 per cent of theory.

A portion of the product is tested for the presence of secondary amine by heating with acetic anhydride (cf. Exp. 168), and distilling. If towards the end of the distillation the boiling-point rises much beyond that of the tertiary amine, it indicates the formation of the acetyl derivative of the secondary amine, in which case the residue of the base should be again heated with methyl iodide and sodium carbonate solution.

D. Quaternary Ammonium Compounds

1. Formation of Quaternary Salts.

(*a*) *From a primary amine.*

Experiment 161.—Trimethyl-*β*-naphthyl-ammonium iodide, $C_{10}H_7{\cdot}N(CH_3)_3I$, **from *β*-naphthylamine.**

$$C_{10}H_7{\cdot}NH_2 + 3CH_3I \rightarrow C_{10}H_7{\cdot}N(CH_3)_3I + 2HI.$$

5 g. of *β*-naphthylamine are boiled with rather more than the theoretical amount of methyl iodide, and 20 ml. of water, in a reflux apparatus, until the whole of the amine goes into solution (3–4 hours). On cooling, the sparingly soluble quaternary salt crystallizes in colourless needles. It is filtered, washed with a very little water, and dried on a porous plate. Yield almost theoretical.

The salt decomposes when heated. On exposure to the air it turns dark coloured owing to the liberation of iodine.

(*b*) *From a tertiary base and an alkyl halide.*

$$R^{i}R^{ii}R^{iii}N + R^{iv}X \rightarrow R^{i}R^{ii}R^{iii}R^{iv}NX.$$

e.g. $C_6H_5N(C_2H_5)CH_2C_6H_5 + CH_3I \rightarrow (CH_3)(C_2H_5)(C_6H_5)(C_6H_5CH_2)NI.$

The rate of the reaction varies considerably with the nature of the alkyl radicals and the halide; thus methyl iodide reacts very quickly with many tertiary amines forming quaternary iodides which have definite melting-points and in which the iodide content can be determined by Volhard's method. These compounds may be used for the recognition of specific amines (see Table XIV).

Experiment 162. — Methyl-ethyl-phenyl-benzyl-ammonium iodide from ethyl-benzyl-aniline and methyl iodide.

A mixture of equivalent quantities of the reagents is placed in an evaporating dish in a desiccator and allowed to stand overnight. The solid product is pressed on porous plate, washed with ether and recrystallized from dilute alcohol. The salt consists of yellow crystals, m.p. 161°.

Salts of this type, in which the four radicals of the ammonium complex all differ from one another, can be resolved into optically active components through the agency of an optically active acid such as *d*-camphor-sulphonic acid (Exp. 128).

2. **Preparation of Quaternary Bases.***

Experiment 163.—Preparation of tetra-methyl-ammonium hydroxide, $N(CH_3)_4OH$.

40 g. of pure dry tetra-methyl-ammonium chloride (estimate the chloride accurately by titration) are dissolved in 80 ml. of absolute alcohol. A filtered solution of potassium hydroxide in methyl alcohol is made, and its strength accurately determined by titration with standard acid; the theoretical amount of this is added to the salt solution. A white precipitate of potassium chloride separates, and is filtered off after the mixture has stood for 1½ hours, the precipitate being washed with a little methyl alcohol. The filtrate is mixed with 45 ml. of water and then subjected to distillation under reduced pressure from a water bath at 35°. After 2 hours, 35 ml. of water are added, and the distillation continued for 1 hour. The solution is now practically free from methyl alcohol. It is removed to a crystallizing dish, and allowed to cool in a desiccator. Partial crystallization takes place; the crystals (about 15 g.) are filtered off, and the solution, after standing

* *Walker* and *Johnston*, J. C. S. 1905, **87**, 955; *Crichton*, P. 1907, **23**, 236.

for some days in the desiccator, deposits a further supply (15 g.) of the crystals.*

The crystalline substance is the penta-hydrate of the base, $N(CH_3)_4OH, 5H_2O$. M.p. 62–63°.

E. Characteristics of the Amines

As a group the amines possess basic properties, and with acids form salts, from which the free bases are liberated by the addition of a strong alkali, such as potassium hydroxide.

The aliphatic amines (alphylamines) are not frequently met with in the laboratory; they differ from the aromatic (arylamines) in being more decidedly basic. Thus their aqueous solutions are strongly alkaline, whereas those of the arylamines are not.

An amine can generally be characterized by the readiness with which it forms salts with mineral acids. This salt formation is indicated by the fact that the amine, although only sparingly soluble in water, dissolves readily in dilute hydrochloric acid. A few amines, of which α- and β-naphthylamine are the most important, yield somewhat sparingly soluble hydrochlorides, and hence do not dissolve in cold hydrochloric acid. That salt formation has occurred can be shown in such a case by comparing the melting-point of the original compound with (*a*) the melting-point of the product obtained by dissolving the base in hot hydrochloric acid, and allowing to cool; (*b*) the melting-point of the product obtained by decomposing the hydrochloride with potassium hydroxide solution.

Distinction between primary, secondary, and tertiary amines.

Primary Amines.

1. *The carbylamine test.*†—A few drops of the amine are warmed (in a fume chamber) with alcoholic potash solution and a few drops of chloroform. The fœtid odour of a carbylamine indicates the presence of a primary amine.

$$R{\cdot}NH_2 + CHCl_3 + 3KOH \rightarrow R{\cdot}N\vdots C + 3KCl + 3H_2O.$$

The test is so delicate that any secondary or tertiary amine containing a trace of a primary amine gives the odour.

* In this experiment it is advisable to protect the solutions from atmospheric carbon dioxide as far as possible, as both potassium hydroxide and the quaternary base readily absorb carbon dioxide.

† *Hofmann*, B. 1870, **3**, 767.

2. *Mustard oil test.*—Primary amines and carbon disulphide condense with the formation of dialkylated thioureas, which are decomposed by boiling concentrated hydrochloric acid yielding *iso*-thiocyanates (mustard oils) with their characteristic odour (cf. Exps. 290, 291).

$$2R{\cdot}NH_2 + CS_2 \rightarrow S{:}C(NHR)_2 + H_2S.$$
$$CS(NHR)_2 + HCl \rightarrow RN{:}C{:}S + RNH_2,\ HCl.$$

3. *Formation of an azo-dye.*—If the compound is a primary arylamine it can yield an azo-dye (cf. Exp. 192). A small amount of the amine is dissolved in dilute hydrochloric acid, a few drops of sodium nitrite solution are added, and the diazo-solution (Exp. 182) is poured into a solution of β-naphthol in aqueous potassium hydroxide. The formation of a brilliant red or reddish-brown precipitate indicates an aromatic primary amine with the NH_2 group attached to the nucleus.

4. *Oxidation to a nitroso-compound.*—The formation of a nitroso-derivative by the oxidation of a saturated aqueous solution of the primary amine with Caro's reagent indicates that the NH_2 group is directly attached to a tertiary carbon atom, i.e. either a carbon of the benzene nucleus or to three alkyl groups, e.g. $CMe_3{\cdot}NH_2$. The nitroso-compounds are colourless solids with definite melting-points, but yield green or blue melts or vapour (cf. Exp. 277).

5. Primary amines yield *monoacyl derivatives* with acyl chlorides or anhydrides (cf. Chap. XIX, A), the majority of which are crystalline with definite melting-points.

Secondary Amines.

1. Nitrous acid reacts with secondary amines yielding *nitrosamines* which give the Liebermann reaction.

Experiment 164.—Methyl-phenyl-nitrosamine from methylaniline.

A few drops of methylaniline are dissolved in dilute hydrochloric acid in a separating funnel and a little sodium nitrite solution added. On shaking, a few drops of oil separate.

$$\begin{matrix} CH_3 \\ C_6H_5 \end{matrix}\!\!>\!NH + HO{\cdot}N{:}O \rightarrow \begin{matrix} CH_3 \\ C_6H_5 \end{matrix}\!\!>\!N{\cdot}N{:}O + H_2O.$$

The oil is extracted with ether, the ethereal solution well washed with water to remove nitrous acid, and the ether

removed.* The oil is then warmed with concentrated sulphuric acid and a little phenol, poured into water and made alkaline with sodium hydroxide, when a deep blue or violet-blue colour is developed.

2. Secondary amines also yield *acyl*-derivatives with acyl chlorides or anhydrides (Chap. XIX, A).

Tertiary Amines.

1. As a rule tertiary alphylamines do not react with nitrous acid, whereas dialphylarylamines yield characteristic *nitroso-derivatives* with the nitroso group *para* to the $\cdot NR_2$ group.

Experiment 165.—*p*-Nitroso-dimethylaniline from dimethylaniline.

2·4 g. of dimethylaniline, $C_6H_5N(CH_3)_2$, are dissolved in a mixture of 5 ml. of concentrated hydrochloric acid and 5 ml. of water, and an aqueous solution of 1·4 g. of sodium nitrite gradually added. The *p*-nitroso-dimethylaniline hydrochloride which is precipitated is filtered off, washed with a little hydrochloric acid, and purified by crystallization from a little hot water. The salt is shaken vigorously with dilute sodium hydroxide solution, and the green nitroso-compound which separates taken up with ether. On removing the ether it is obtained as green plates. M.p. 85°.

2. Tertiary amines do not react with acyl chlorides or anhydrides.

3. Most tertiary amines combine readily with methyl iodide, yielding crystalline quaternary ammonium salts (see section D of this chapter). On mixing the tertiary amine with methyl iodide a solid is formed and can be crystallized. A determination of the iodine content of the salt by Volhard's method can be used for ascertaining the molecular weight of the amine.

F. Estimation of Amino-Groups in Primary Arylamines

A standard solution of the amine is made by dissolving a known weight in about three times as much concentrated hydrochloric acid and diluting with water to a definite volume. A suitable strength is from 5 to 10 g. of base per litre.

Five titration flasks are taken and 10 ml. of the amine solution placed in each. To these are added respectively 5,

* It is necessary to remove all traces of nitrous acid or nitrite as these also give the Liebermann reaction (see Exp. 141).

10, 15, 20, 25 ml. of an approximately 0·1 N. solution of sodium nitrite; they are allowed to stand for 15 minutes in a cool place (5°) with occasional stirring. At the end of this period each flask is tested for free nitrous acid by removing a drop with the aid of a glass rod and testing with potassium iodide-starch paper. Supposing the first flask to show excess is the one containing 15 ml. of nitrite, then the tests are repeated in a similar manner with 11, 12, 13, 14, 15 ml. of nitrite, again allowing to stand for 15 minutes before testing for nitrous acid. If the one with 14 ml. shows excess, then a third series of tests is made with 13·2, 13·4, 13·6, 13·8 ml., and the final result will give the amount of nitrite required to an accuracy of one per cent.

The nitrite solution used can be simultaneously standardized in a manner similar to the above by using a known weight of a pure amine, e.g. *p*-toluidine.

G. Estimation of Imino-Groups in Secondary Amines *

A weighed quantity of the secondary amine is introduced into a perfectly dry litre flask, which is fitted with a two-holed rubber stopper which carries a dropping funnel and a straight glass tube. This glass tube is connected by means of rubber with a second glass tube fitting into the neck of the funnel and reaching practically to the bottom of the body of the funnel. The amine is mixed with 50 ml. of a 7 per cent solution of pure acetic anhydride in dry xylene, and after standing for an hour water is added from the dropping funnel, so that the displaced air is made to bubble through the water in the funnel and no anhydride vapour is lost. The acetic acid present is then titrated with standard barium hydroxide (Chap. VII, A), using phenolphthalein as indicator.

The method may be used for estimating the amount of secondary amine in a solution, provided the solvent does not react with acetic anhydride, and also for determining the amount of secondary amine mixed with a primary or with a primary and tertiary, provided the amount of primary amine is first determined by some other method and the quantity of acetic anhydride which reacts with this allowed for in the final calculation.

* *Vaubel*, J. S. C. I. 1893, 12, 954.

XIX. ACYL DERIVATIVES

Alcohols of all types, phenols, and primary and secondary amines, yield *acyl-derivatives* by the replacement of the hydrogen of the OH, NH_2, or NH groups by acyl radicals. The commonest acyl derivatives are the *acetyl*, $CO\cdot CH_3\cdot$, *benzoyl*, $C_6H_5\cdot CO\cdot$, and 3:5-dinitrobenzoyl, and these are of considerable practical importance. The formation of such derivatives is used not merely to indicate the presence of OH, NH_2, or NH groups, but also to determine the individual substance under examination, as the acetyl and benzoyl derivatives crystallize well and have definite melting-points, with the exception of the acetyl and benzoyl derivatives of the lower monohydric alcohols, which are best identified by the formation of their solid 3:5-dinitrobenzoyl derivatives (cf. Exp. 115).

A. Acyl Derivatives of Primary and Secondary Amines. (S.B. Chap. XXI, F)

The preparation of the anilide, toluidide, &c., of an organic acid can usually be conducted in much the same manner as the preparation of the amide of the acid (Chap. XIV, B).

Method I.—By the elimination of water from the salt formed by the union of the acid and amine. As examples, we have the formation of acetanilide from aniline and acetic acid, and of benzanilide from aniline and benzoic acid.

$$R\cdot C{\overset{\displaystyle O}{\lessgtr}}ONH_3R' \rightarrow R\cdot C{\overset{\displaystyle O}{\lessgtr}}NHR' + H_2O.$$

This is the cheapest method for the preparation of large quantities of an anilide, but for rapid laboratory preparations methods based on the use of the acyl chloride or anhydride are always used (cf. Exps. 168–171).

Experiment 166.—Acetanilide (acetphenylamide), $CH_3\cdot CO\cdot NH\cdot C_6H_5$, **from aniline and acetic acid.***

A mixture of equal weights of pure aniline and glacial acetic acid, with 2–3 per cent of anhydrous zinc chloride, is gently boiled for three hours in a round-bottomed flask fitted with a

* *Williams* J. C. S. 1864, 206; *Häussermann*, J. S. C. I. 1914, **33**, 1223.

reflux condenser. The hot liquid is then poured into excess of water, filtered, and washed with cold water. The crude acetanilide may be crystallized from a mixture of alcohol and water, or from water alone, although it is only sparingly soluble in the latter. If the solution is dark coloured it is boiled with animal charcoal, and filtered by means of a hot-water funnel (fig. 15). As the solution cools, rhombic plates, m.p. 114°, are deposited.

Experiment 167.—Benzanilide, $C_6H_5{\cdot}CO{\cdot}NH{\cdot}C_6H_5$, **from aniline benzoate.**

A mixture of 15 g. of aniline and an equivalent amount of benzoic acid is heated in a retort at 180° and the temperature raised gradually to 225°; a further quantity of aniline is then added and the heating continued. The hot mass is poured into a dish, allowed to solidify, powdered, washed in turn with dilute hydrochloric acid, water, dilute sodium hydroxide, and finally washed with water, dried, and recrystallized from alcohol. It forms glistening plates, m.p. 161–162°.

Method II.—By the inter-reaction of an acid chloride, or more frequently an acid anhydride, and the amine * (primary or secondary):

$$C_6H_5{\cdot}CO{\cdot}Cl + 2C_6H_5{\cdot}NH_2 \rightarrow C_6H_5{\cdot}CO{\cdot}NH{\cdot}C_6H_5 + C_6H_5{\cdot}NH_2,\ HCl.$$

$$C_6H_5NH_2 + \begin{matrix} CH_3{\cdot}CO \diagdown \\ \quad O \\ CH_3{\cdot}CO \diagup \end{matrix} \rightarrow CH_3{\cdot}CO{\cdot}NH{\cdot}C_6H_5 + CH_3{\cdot}CO_2H.$$

The acetic anhydride method is extremely convenient when it is desired to prepare a small amount of an acetyl derivative for the identification of an amine.

Experiment 168.—Acet-*o*-toluidide, $CH_3{\cdot}C_6H_4{\cdot}NH{\cdot}CO{\cdot}CH_3$, **from *o*-toluidine and acetic anhydride.**

$$CH_3{\cdot}C_6H_4{\cdot}NH_2 + (CH_3{\cdot}CO{\cdot})_2O = CH_3{\cdot}C_6H_4{\cdot}NH{\cdot}CO{\cdot}CH_3 + CH_3{\cdot}CO{\cdot}OH.$$

1 g. of *o*-toluidine is heated for two minutes in a test tube with an equal weight of acetic anhydride, and the hot mixture then poured into 10 ml. of cold water. When the excess of acetic anhydride has been decomposed the solid is filtered, washed with water, and recrystallized from alcohol. It forms long needles, m.p. 110°.

* *H. Franzen*, B. 1909, **42**, 2465.

If the amine is boiled for some time with an excess of acetic anhydride, a diacetyl derivative, e.g. $CH_3 \cdot C_6H_4 \cdot N(CO \cdot CH_3)_2$, is formed together with the monoacetyl derivative. The presence of ortho substituents facilitates the formation of diacetyl derivatives.

Experiment 169.—Diacet-*o*-toluidide. $CH_3 \cdot C_6H_4 \cdot N(CO \cdot CH_3)_2$. A mixture of 10 g. of *o*-toluidine and 38 g. of acetic anhydride is boiled for an hour in a flask fitted with an upright air condenser and a calcium chloride tube. The mixture is then transferred to a distilling flask and distilled under reduced pressure; acetic acid and the excess of acetic anhydride pass over first; then the diacetyl derivative distils over at 152–153° under 20 mm. pressure, and a small amount of monoacetyl derivative (1–2 g.) is left in the flask. The diacetyl compound is a colourless liquid which solidifies gradually to well-developed pyramids; m.p. 18°. Yield, 14·5 g. It is somewhat unstable, and readily gives up one acetyl group in the form of acetic acid when in contact with water.

In order to avoid the formation of a diacetyl derivative in the preparation of a monoacetyl compound an aqueous solution of acetic anhydride may be used *—12·3 g. in 120 ml. of water—together with a solution of the base in dilute acetic acid. The yield is practically theoretical.

Amino-derivatives of sulphonic acids cannot, as a rule, yield acetyl derivatives when warmed with acetic anhydride. The simplest method is to use an aqueous solution of a normal salt, e.g. sodium or calcium, and add the requisite amount of acetic anhydride.

Compounds which react too vigorously with acetic anhydride can be acetylated by using *cold* aqueous or alcoholic solutions of the anhydride. Such a compound is *p*-amino-azobenzene (Exp. 190), the acetyl derivative of which has m.p. 144°. In cases where acetic anhydride acts slowly the addition of a catalyst is advisable, e.g. one or two drops of concentrated sulphuric acid.†

Experiment 170.—*s*-Tribromoacetanilide.

1 g. of *s*-tribromaniline (Exp. 41) is dissolved in 20 g. of acetic anhydride with the addition of 2 drops of concentrated sulphuric acid and kept for 10 minutes at room temperature, then poured into warm water. M.p. 232°.

* *Lumière* and *Barbier*, Bull. 1905, [iii], **33**, 783.

† *Smith* and *Orton*, J. C. S. 1908, 1242.

Aromatic acyl derivatives can be obtained by the careful addition of the acyl chloride to the amine in an open dish. The method, however, has the disadvantage that half the amine is used up in combining with the hydrogen chloride formed during the reaction. The process is usually modified by the addition of either (*a*) sodium hydroxide solution, or (*b*) a tertiary base such as pyridine, α-picoline or dimethylaniline. Method (*a*) is known as the *Schotten-Baumann* * *process* of acylation.

$$C_6H_5\cdot CO\cdot Cl + CH_3\cdot C_6H_4\cdot NH_2 + NaOH \rightarrow C_6H_5\cdot CO\cdot NH\cdot C_6H_4\cdot CH_3 + NaCl + H_2O.$$

Experiment 171—Benzoyl-*p*-toluidide, $C_6H_5\cdot CO\cdot NH\cdot C_6H_4\cdot CH_3$.

2 g. of *finely divided* *p*-toluidine are mixed with 10 ml. of a 10 per cent aqueous solution of sodium hydroxide, and excess of benzoyl chloride (2 ml.) is added gradually to the warm mixture, which is frequently shaken. Thorough shaking is essential, and the best method is to cork the flask and agitate as vigorously as possible. If any excess of benzoyl chloride is left, it is destroyed by warming with a further amount of sodium hydroxide solution. The mixture is then poured into water, filtered, the precipitate washed with water, dried, and recrystallized from alcohol. M.p. 158°.

B. Acyl Derivatives of Alcohols and Phenols

Method I.—The acetyl derivatives are usually prepared by heating the hydroxy compound with an excess of acetic anhydride and *anhydrous* sodium acetate (Exp. 13). The latter is sometimes replaced by zinc chloride, a few drops of concentrated sulphuric acid, or pyridine.

Experiment 172.—Pyrogallol triacetate, $C_6H_3(O\cdot CO\cdot CH_3)_3$.

A mixture of 5 g. of pyrogallol and the same weight of freshly fused anhydrous sodium acetate is boiled with 15 g. of acetic anhydride in a small round-bottomed flask fitted with a reflux condenser. After thirty minutes the mass is poured into water and left until the oil, which separates at first, solidifies. The solid is then filtered by means of the pump, washed with water, dried, and crystallized from benzene or dilute alcohol. M.p. 165°. Yield, 94 per cent of theory.

* B. 1886, **19**, 3219.

Experiment 173.—Hexa-acetyl derivative of mannitol,* $OAc \cdot CH_2 \cdot [CH \cdot OAc]_4 \cdot CH_2 \cdot OAc$.

5 g. of mannitol, $OH \cdot CH_2[CH \cdot OH]_4 \cdot CH_2 \cdot OH$, 20 g. of acetic anhydride, and a small piece of anhydrous zinc chloride are boiled for an hour. The mass is poured into water, and the solid thus obtained crystallized from alcohol or glacial acetic acid. It forms flat, snow-white prisms, m.p. 119°. Yield nearly theoretical.

Sugars can be acetylated by a mixture of acetic anhydride and acetic acid at room temperature in the presence of a little perchloric acid.†

The cyclic pyranoses yield two stereoisomeric poly-acetyl derivatives. Thus *d*-glucopyranose yields α- and β-pentacetyl-glucoses corresponding with the α- and β-methyl glucosides (S.B. Chap. LVI, 3).

Experiment 174.—α-Pentacetyl-glucose from glucose.

To a mixture of 1 g. anhydrous zinc chloride ‡ and 25 ml. acetic anhydride 5 g. of glucose are added, and the mixture heated on the water bath for 1 hour with occasional shaking and then poured into 250 ml. cold water. The oily product solidifies on stirring, and is then filtered, washed with water, and recrystallized from alcohol. Yield, 7·5 g.; m.p. 110–111°.

For the preparation of the β-compound the zinc chloride is replaced by 2·5 g. anhydrous sodium acetate and the product crystallized from alcohol. Yield, 10 g.; m.p. 130–131°. When heated with a little zinc chloride and acetic anhydride it yields the α-compound.

Method II.—Benzoates are usually prepared by the Schotten-Baumann method.

Experiment 175.—Glyceryl tribenzoate, $C_3H_5(O \cdot CO \cdot C_6H_5)_3$.‖

3 g. of glycerol are shaken with sodium hydroxide solution (10 per cent solution) and a considerable excess of benzoyl chloride, as in Exp. 171. The dry product is crystallized from light petroleum, and has m.p. 76°.

Practically all hydroxy derivatives can be benzoylated by this method, and other acid chlorides, e.g. phenylacetyl chloride, may be substituted for benzoyl chloride.

* B. 1879, **12**, 2059.
† *Nature*, 1948, **161**, 349.
‡ Work rapidly to avoid absorption of moisture.
‖ B. 1886, **19**, 3221; M. 1889, **10**, 393.

Experiment 176.—Acetyl-salicylic acid (Aspirin) from salicylic acid.

$$OH{\cdot}C_6H_4{\cdot}CO_2H \rightarrow OAc{\cdot}C_6H_4{\cdot}CO_2H.$$

7·5 ml. acetyl chloride are added gradually 1 ml. at a time to 10 g. salicylic acid and 7 ml. dry pyridine with vigorous shaking. The reaction is controlled by maintaining the temperature at 50–60° by external cooling until all the acetyl chloride is added and the reaction completed by heating on the water bath for 15 minutes. The mixture is then cooled and poured on to a mixture of crushed ice and water. The solid product is recrystallized from a mixture of equal volumes of acetic acid and water. Yield, 11 g.; m.p. 136°.

Experiment 177. — Ethyl 3:5-dinitrobenzoate, $(NO_2)_2C_6H_3{\cdot}CO_2Et$.

1 g. of 3:5-dinitrobenzoyl chloride prepared from the acid (Exp. 115) is warmed for 10 minutes with 1 ml. of ethyl alcohol; the mixture is poured into water and the dry solid recrystallized from methyl alcohol. M.p. 94°. Yield theoretical. The methyl ester obtained in a similar manner has m.p. 109°, and the chloride is an excellent reagent for characterizing the two alcohols.

For the preparation of the dinitro-esters derived from other alcohols or phenols the addition of a little pyridine is advisable.

C. Acylation of Aminophenols

A compound containing both amino- and hydroxy-groups can be acylated so that both the O hydrogen and the N hydrogen are replaced by acyl groups. Thus *p*-aminophenol benzoylated by the Schotten-Baumann method gives the dibenzoyl derivative,

$$C_6H_5CO{\cdot}O{\cdot}C_6H_4{\cdot}NH{\cdot}COC_6H_5.$$

1:2-Amino-naphthol, however, yields the monobenzoyl derivative,

$$HO{\cdot}C_{10}H_6{\cdot}NH{\cdot}COC_6H_5,$$

under the conditions given below.

Experiment 178.—2-Hydroxy-1-benzoyl-naphthylamine.

A mixture of 2 g. of 1:2-amino-naphthol hydrochloride, 1 g. anhydrous sodium acetate, and a solution of 2 g. benzoic anhydride in 10 ml. glacial acetic acid is warmed on the water

bath for 1·5 hours, then poured into cold water and the solid product recrystallized from dilute alcohol. M.p. 248°.

D. Removal of Acyl Radicals

The acetyl and benzoyl derivatives of amines and of alcohols can be hydrolysed by boiling with mineral acids or with alkalis. Since the acyl derivatives of alcohols are esters, this is merely a further example of the readiness with which most esters can be saponified (Chap. XII, D). The acyl derivatives of amines are more difficult to hydrolyse, e.g. acetanilide must be boiled with fairly concentrated potassium hydroxide or a mineral acid for some hours before the hydrolysis has proceeded to any appreciable extent. The products in all cases are an amine and an acid or their salts. Benzanilide, and the benzoyl derivatives of amines generally, cannot be hydrolysed by boiling with an alkali solution, but are decomposed when heated with solid potash, or when boiled with concentrated hydrochloric acid.

E. Estimation of Acetyl Radicals

The number of hydroxyl radicals contained in a given alcohol or phenol can be ascertained by preparing the acetyl derivative by the method described in Exps. 172 and 173, hydrolysing a known weight of the acetyl derivative with *p*-toluene-sulphonic acid, and titrating the amount of acetic acid by means of standard barium hydroxide solution.

An aqueous solution of *p*-toluene-sulphonic acid of 10 per cent strength is steamed until the distillate is neutral and is then ready for use.

Experiment 179.—Determine the percentage of acetyl radical present in hexa-acetyl-mannitol.

About 0·2 g. of the substance and 100 ml. of the 10 per cent *p*-toluene-sulphonic acid solution are used. Steam is blown through at such a rate that about 400 ml. of distillate are collected per hour. The distillation is continued until the liquid which passes over is neutral (1·5–3 hours), and the whole distillate is titrated with standard barium hydroxide. *N.B.*—The distillation should be conducted in a room fairly free from carbon dioxide, or the distillate should be protected from the atmospheric carbon dioxide by means of a soda-lime tube.

The acetyl radicals in an acetylated amine can be estimated in a similar manner, but the process is more tedious as the acetyl derivatives of amines are hydrolysed but slowly.

F. 2:4-Dinitro- and 2:4:6-Trinitro-1-Chlorobenzene as Reagents

These substances yield readily crystallizable derivatives with primary and secondary amines and also with hydroxy-compounds. They are therefore usefully applied for the recognition of specific amines and, to a less extent, of alcohols and phenols.

2:4-Dinitrochlorobenzene is a yellow crystalline solid, m.p. 50°. For the preparation of derivatives, approximately equivalent amounts of the reagent and of the amine, alcohol or phenol are mixed and heated together in a water bath for several minutes and the product crystallized from ethyl alcohol. (See Tables IV, V, XIII and XIV.)

By condensation with hydrazine, N_2H_4, it yields 2:4-dinitrophenylhydrazine, which is itself a useful reagent for the characterization of compounds containing carbonyl groups. (See Chap. XXII, C, and Tables XI and XII.)

Experiment 180.—2:4-Dinitrophenylhydrazine,

$$C_6H_3(NO_2)_2NH{\cdot}NH_2.$$

10 g. 2:4-dinitrochlorobenzene are dissolved in 25 ml. alcohol, and a mixture of 5 ml. hydrazine hydrate (50 per cent), 10 ml. alcohol and 2·5 ml. strong ammonia solution added gradually. The product separates out quickly and is filtered off, washed with alcohol and then with water. Yield quantitative; m.p. 197° (dec.).

2:4:6-Trinitrochlorobenzene (picryl chloride, Exp. 119) provides a similar series of derivatives, e.g.

$$\underset{\text{picryl chloride}}{C_6H_2(NO_2)_3Cl} + \underset{\text{methylaniline}}{C_6H_5NH{\cdot}CH_3} \rightarrow \underset{\text{picrylmethylaniline}}{C_6H_2(NO_2)_3N(CH_3)C_6H_5}.$$

The general method is to add a slight excess of the amine to a 2 per cent solution of picryl chloride in alcohol and boil for several minutes. Water is added, the solution cooled, the precipitate filtered off and washed with dilute alcohol. It is then crystallized from alcohol or acetic acid.

Experiment 181.—Picrylmethylaniline.*

5 g. picryl chloride and 4·5 g. methylaniline are dissolved in 50 ml. alcohol and boiled on a water bath for an hour. On cooling, a dark-red crystalline powder separates which is recrystallized from alcohol.

The compound is dimorphic; the crystals which separate from cold alcohol have m.p. 108°; from hot alcohol, m.p. 128°.

XX. DIAZONIUM SALTS AND THEIR USES †

A. Preparation of Diazonium Salts

The diazo-compounds or diazonium salts are produced by the action of nitrous acid in the cold on primary arylamines or their salts, e.g.

$$C_6H_5NH_2, HCl + HONO \rightarrow C_6H_5\overset{\overset{N}{\vdots}}{N}\cdot Cl + H_2O.$$

The salts may be isolated in solid form by the addition of alcohol and ether to their aqueous solutions, or by the addition of the theoretical amount of amyl nitrite to a solution of a salt of the amine in alcohol and acid.‡ Since the compounds in the dry state are very explosive, and as they are generally used in aqueous solution, their isolation is not often necessary. (S.B. Chap. XXII. A.)

Experiment 182.—Phenyl-diazonium chloride, $C_6H_5N_2Cl$.

10 g. of aniline (1 mol) are dissolved in 50 ml. of a mixture of equal volumes of concentrated hydrochloric acid and water (excess: more than two mols), and the mixture is well cooled by means of ice. 8–9 g. of sodium nitrite (more than 1 mol) dissolved in 20 ml. of water are then added slowly from a dropping funnel, the end of which dips under the solution of amine; the mixture is kept well agitated during the addition and the temperature is not allowed to rise. The addition of the nitrite solution is continued until a drop of the mixture,

* *Wedekind*, B. 1900, **33**, 434; *Sudborough and Picton*, J. C. S. 1906, **89**, 582.

† *P. Griess*, A. 1860, **113**, 201; 1861, **117**, 1; 1862, **121**, 257; 1866, **137**, 39.

‡ *Knoevenagel*, B. 1895, **28**, 2049.

withdrawn by means of a glass rod, indicates the presence of free nitrous acid by giving a blue coloration with starch-potassium iodide paper.

A solution prepared in this manner may be used for the following experiments.

This process, usually termed *diazotizing*, is of very general application, and by its means all aromatic compounds possessing an amino-group directly attached to the benzene nucleus can be converted into diazonium salts, the salt obtained varying with the mineral acid used. Practically all the salts are soluble in water and the solutions are good electrolytes, resembling aqueous solutions of quaternary ammonium salts.

The compounds are characterized by a remarkable activity, and can be used for the preparation of numerous groups of compounds, as shown in the experiments described in this chapter. One of the most general properties is the readiness with which nitrogen is eliminated and the $—N_2X$ group replaced by some other univalent group.

Certain amines do not dissolve readily in dilute mineral acids, either owing to the fact that they do not form salts in dilute aqueous solution or that the salts are sparingly soluble. Under such circumstances the amine or salt in a finely divided state is suspended in the acid and diazotized in the usual manner. When completely diazotized a clear liquid should be obtained; if any insoluble amine remains it can be removed by filtration.

B. Replacement of the Diazo-Group by Iodine

Experiment 183.—Phenyl iodide,* C_6H_5I, from aniline.

$$C_6H_5N_2Cl + KI \rightarrow C_6H_5N_2I + KCl$$
$$C_6H_5N_2I \rightarrow C_6H_5I + N_2.$$

An excess of potassium iodide solution (25 g. in 50 ml. water) is added to a diazo-solution prepared according to Exp. 182, and the mixture heated gradually on a water bath until no more evolution of nitrogen occurs. Phenyl iodide separates as a heavy dark oil, which is steam-distilled. The distillate is extracted with ether, and the ethereal solution washed with water and dilute sodium hydroxide solution until

* *Griess*, A. 1866, 137, 76.

all free iodine is removed, then dried with calcium chloride and distilled. Yield, 18–20 g. It is a heavy, yellow liquid; b.p. 190°; D^{15}, 1·833.

C. Replacement of the Diazo- by the Hydroxyl-Group

The diazonium salts, more especially the sulphates, decompose when boiled with water, yielding nitrogen and phenols.

Experiment 184.—Phenol, $C_6H_5{\cdot}OH$, **from aniline.**

$$C_6H_5N_2{\cdot}HSO_4 + H_2O \rightarrow C_6H_5OH + N_2 + H_2SO_4.$$

10 g. of aniline are added to the hot solution obtained by pouring 20 g. of concentrated sulphuric acid into 50 ml. of water. The resulting solution is cooled and diazotized as in Exp. 182. The product is heated gently on a water bath for half an hour, and then distilled with steam. The distillate is extracted with ether, the ethereal solution dried with fused sodium sulphate, and fractionated. The phenol distils over at 183°, and solidifies to colourless crystals, m.p. 43°. Yield, 6–8 g. (For properties of phenols, see Chap. XVII, B.)

D. Replacement of the Diazo-Group by Chloro-, Bromo- and Nitrile Radicals (Sandmeyer's Reaction). *

The diazonium halides and cyanides are decomposed by the addition of solutions of the corresponding cuprous salts in acid solution, with the formation of halogen or cyanogen derivatives of benzene and evolution of nitrogen.

$$C_6H_5N_2Cl\,[+Cu_2Cl_2] \rightarrow C_6H_5Cl + N_2\,[+Cu_2Cl_2].$$

Experiment 185.—Monochlorobenzene, C_6H_5Cl, **from aniline.**

(*a*) Preparation of a 10 per cent solution of cuprous chloride. The reactions involved are as follows:

$$CuSO_4 + 2NaCl \rightarrow CuCl_2 + Na_2SO_4$$
$$CuCl_2 + Cu \rightarrow Cu_2Cl_2.$$

25 g. of cupric sulphate crystals ($CuSO_4$, $5H_2O$) and 12 g. of pure sodium chloride are dissolved in 50 g. of water in a

* *Sandmeyer*, B. 1884, 17, 1633, 2650.

tared flask. The solution is heated to boiling, and then 100 g. of concentrated hydrochloric acid and 13 g. of copper filings (excess) are added, and the flask heated until the contents become colourless. During this process 6·4 g. of copper will dissolve. Concentrated hydrochloric acid is then added, until the total weight is 203·6 g. The solution, weighing 197 g., contains 19·7 g. of cuprous chloride.

(*b*) 20 g. of aniline are diazotized as described in Exp. 182, and the solution of benzenediazonium chloride thus formed is run gradually into 100 g. of the cuprous chloride solution, heated to boiling in a flask fitted with a reflux condenser. The yellow precipitate which is formed on the introduction of the diazo-solution disappears almost immediately with evolution of nitrogen. The chlorobenzene formed is distilled with steam, extracted with ether, the ethereal solution dried over calcium chloride, and fractionated. Yield, 18 g., i.e. 75 per cent of theory.

It is a colourless liquid with pleasant odour: b.p. 132°; $D^{15°}$, 1·110.

Experiment 186.—*m*-Nitrochlorobenzene, $C_6H_4Cl{\cdot}NO_2$ (1:3), **from *m*-nitraniline.**

$$C_6H_4\begin{cases}NH_2\ (1)\\NO_2\ (3)\end{cases} \rightarrow C_6H_4\begin{cases}Cl\ \ (1)\\NO_2\ (3).\end{cases}$$

4 g. of *m*-nitraniline (Exp. 152) are dissolved in a mixture of 7 g. of concentrated hydrochloric acid and 100 g. of water, and 20 g. of the 10 per cent solution of cuprous chloride (Exp. 185) added. The mixture is heated to boiling in a flask, and then decomposed by the addition, through a dropping funnel, of 2·5 g. of sodium nitrite dissolved in 20 g. of water. A heavy brown oil separates out, which solidifies on standing in the cold. M.p. 44·4°; b.p. 235·6° (corr.).

The amino-group can be replaced by bromine in much the same manner. A solution of cuprous bromide is prepared as follows:

A mixture of 12·5 g. of cupric sulphate crystals (1·5 mol), 36 g. of potassium bromide (3 mols), 80 ml. of water, 11 g. of concentrated sulphuric acid (1 mol), and 20 g. of copper turnings is boiled in a flask fitted with a reflux condenser until practically decolorized. This solution can then be used in the same manner as the cuprous chloride solution in Exps. 183 and 186.

Experiment 187.—Benzonitrile, $C_6H_5{\cdot}CN$, from aniline.

$$2C_6H_5N_2Cl + 2CuCN, KCN \rightarrow 2C_6H_5CN + 2N_2 + Cu_2Cl_2 + 2KCN.$$

(*a*) Preparation of potassium cuprous cyanide solution.

N.B.—*Cyanogen is evolved during this reaction; the preparation must therefore be conducted in a fume chamber with a good draught, great care being taken not to breathe the fumes.*

25 g. of cupric sulphate crystals are dissolved in 150 g. of water, and 28 g. of 96 per cent potassium cyanide added to the hot solution. The precipitate at first formed soon redissolves. The product contains 18 g. of cuprous cyanide, in the form of potassium cuprous cyanide, in 200 g. of solution.

(*b*) The cuprous cyanide solution is heated to 90°, and a solution of benzene-diazonium chloride, prepared from 10 g. of aniline, as in Exp. 182, added gradually through a dropping funnel. The oil which separates is distilled with steam, the distillate extracted with ether, the ethereal solution washed with dilute sodium hydroxide and sulphuric acid solutions, dried with calcium chloride, and fractionated. Yield, 6–7 g., i.e. 60–65 per cent of theory. It is a colourless oil; b.p. 191°; D^{0°, 1·023.

This reaction is one of the most important methods for the preparation of aromatic nitriles (cf. Chap. XIV, D).

E. Action of finely divided Copper on Diazonium Salts (Gattermann's Method) *

Finely divided copper acts similarly to cuprous salts in inducing the decomposition of solutions of diazonium salts.

Experiment 188.—*p*-Chlorotoluene, $C_6H_4Cl{\cdot}CH_3$ (1:4), from *p*-toluidine.

$$C_6H_4\Big\langle\begin{matrix}CH_3\ (1)\\ NH_2\ (4)\end{matrix} \rightarrow C_6H_4\Big\langle\begin{matrix}CH_3\ (1)\\ Cl\ \ (4).\end{matrix}$$

12 g. of *p*-toluidine are diazotized as described in Exp. 182, and 30 g. of the moist copper powder are gradually added; the product is distilled with steam, the distillate taken up with ether, the ethereal solution dried with calcium chloride and distilled. The *p*-chlorotoluene is an oily liquid; b.p. 163°.

The action of finely divided copper or zinc on an aqueous-

* *Gattermann*, B. 1890, **23**, 1218.

alcoholic solution of a diazonium salt can also be used for introducing an aryl-group in place of the diazo-group; thus benzenediazonium sulphate, under these conditions, can give a 22 per cent yield of diphenyl.*

$$C_6H_5N_2{\cdot}HSO_4 \rightarrow C_6H_5{\cdot}C_6H_5.$$

The alcohol is oxidized to acetaldehyde, and several complex hydrocarbons such as $C_6H_5{\cdot}C_6H_4{\cdot}C_6H_5$, $C_6H_5{\cdot}C_6H_4{\cdot}C_6N_4{\cdot}C_6H_5$ are also formed.

Numerous diphenyl derivatives have been synthesised by the action of a diazonium hydroxide on an aromatic hydrocarbon.†

$$NO_2{\cdot}C_6H_4{\cdot}N_2{\cdot}OH + C_6H_6 \rightarrow NO_2{\cdot}C_6H_4{\cdot}C_6H_5 + N_2 + H_2O.$$

F. Interaction of Diazonium Salts with Primary Arylamines: Formation of Diazo-amino-Compounds. (S.B. Chap. XXII, B.)

Diazonium salts condense with primary arylamines, yielding diazo-amino-compounds (Griess). The same product may be attained in one operation by taking two molecular proportions of the amine, and adding only sufficient acid and nitrite solution to diazotize one molecule. The diazonium salt thus formed reacts with the excess of amine, forming the diazo-amino-compound, e.g.

$$C_6H_5N_2{\cdot}HSO_4 + H_2N{\cdot}C_6H_5 \rightarrow C_6H_5N{:}N{\cdot}NH{\cdot}C_6H_5 + H_2SO_4.$$

Experiment 189.—Diazo-amino-benzene, $C_6H_5N{:}N{\cdot}NHC_6H_5$, **from aniline.**‡

10 g. of aniline are dissolved in 3 g. of concentrated sulphuric acid diluted with 300 ml. of water. The solution is brought to a temperature of 27° by heating in a water bath, and an aqueous solution of 3·6 g. of sodium nitrite added. If the temperature rises above 30° the mixture is quickly cooled, ice being added if necessary. (The limits of temperature for obtaining a good yield are 25–35°.) Immediately after the addition of the nitrite solution a yellow precipitate begins to

* Ibid. 1226.

† *Gomberg* and others, J. A. C. S. 1924, 2339; 1926, 1372; Org. Synth. 1928, 43.

‡ *Staedel* and *Bauer*, B. 1886, 19, 1952.

separate, and this separation is complete after thirty minutes. The precipitate is removed, washed with cold water, and dried on a porous plate at the ordinary temperature. Yield, 97–98 per cent of theory.

The substance crystallizes from light petroleum in golden-yellow plates. It melts at 98°, but explodes if heated above its melting-point. It is insoluble in water, sparingly soluble in cold, but readily in hot alcohol, ether, and benzene.

Chemical properties of the Diazo-amino-Compounds.—The hydrogen atom of the :NH group is replaceable by metals, e.g. diazo-amino-benzene in ethereal solution reacts with metallic sodium, yielding the compound $C_6H_5N{:}N{\cdot}NNa{\cdot}C_6H_5$, which is readily decomposed by water.

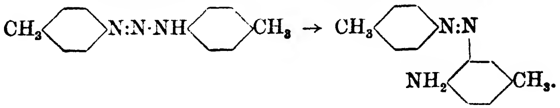
An alcoholic solution of diazo-amino-benzene, treated with silver nitrate solution, deposits reddish crystals of the corresponding silver salt.

In many of their reactions the diazo-amino-compounds resemble diazonium salts, but are not nearly so decomposable.

Molecular Rearrangement of Diazo-amino-Compounds: Formation of Amino-azo-Derivatives.

The diazo-amino-compounds in the presence of a small amount of the amine hydrochloride are transformed into the isomeric amino-azo-compounds. The para-derivative is usually obtained, but if the para-position is already occupied by a substituent, an ortho-amino-derivative results.

$$C_6H_5N{:}N{\cdot}NH{\cdot}C_6H_5 \rightarrow C_6H_5N{:}\overset{1}{N}{\cdot}C_6H_4{\cdot}\overset{4}{N}H_2.$$



Experiment 190.—*p*-Amino-azobenzene, $C_6H_5N{:}\overset{1}{N}{\cdot}C_6H_4{\cdot}\overset{4}{N}H_2$, **from diazo-amino-benzene.***

5 g. of diazo-amino-benzene are dissolved in 10–15 g. of aniline, and 2·5 g. of aniline hydrochloride are added. The mixture is warmed to 40° for an hour, and then allowed to stand for twenty-four hours, when an excess of fairly strong hydrochloric acid is quickly added (the temperature must not rise above 70°), and the solution allowed to cool. Amino-azo-benzene hydrochloride separates as fine crystals, which are

* *Staedel* and *Bauer*, B. 1886, **19**, 1953.

washed several times with dilute hydrochloric acid. The yield is nearly quantitative. The free base is obtained by treating the hydrochloride with dilute ammonia solution. It crystallizes from dilute alcohol in brownish-yellow needles; m.p. 126°

Amino-azobenzene is a feebly basic primary arylamine. It does not form stable salts with weak acids like acetic, but does so with strong mineral acids. It can be diazotized, and the resulting diazonium salt " coupled " with phenols, amines, &c. (cf. Exps. 191, 192), when tetrazo-compounds are formed.

$$C_6H_5N{:}N\cdot C_6H_4\cdot N_2Cl + C_6H_5\cdot OH \rightarrow C_6H_5N{:}N\cdot C_6H_4\cdot N{:}N\cdot C_6H_4\cdot OH + HCl.$$

G. Interaction of Diazo-Compounds with Secondary Amines: Diazo-imino-Compounds

In alkaline solution the diazo-compounds react with secondary amines of all types, yielding a diazo-imino-compound, e.g. $C_6H_5\cdot N(CH_3)\cdot N{:}NPh$, which is decomposed by acid regenerating the secondary amine and a diazonium salt.

H. Azo-dyes. (S.B. Chap. XXII, E; LIX, B)

The diazonium salts " couple " with tertiary amines and also with alkaline solutions of phenols, yielding dialkylamino-azo- and hydroxy-azo-derivatives, many of which are important dyes. The majority of these dyes also contain sulphonic acid groups, as the presence of such groups renders the compound more readily soluble in water. Certain secondary and even primary amines, e.g. *m*-phenylene-diamine, can also " couple " with diazonium salts.

Experiment 191.—Helianthine (methyl-orange),

$$C_6H_4 \begin{cases} SO_3Na \\ N{:}N\cdot C_6H_4\cdot N(CH_3)_2, \end{cases}$$

from sulphanilic acid and dimethylaniline.

$$SO_3Na\cdot C_6H_4\cdot NH_2 \rightarrow SO_3Na\cdot C_6H_4\cdot N_2OH$$

$$SO_3Na\cdot C_6H_4\cdot N_2\cdot OH + C_6H_5\cdot N(CH_3)_2$$

$\rightarrow SO_3Na\cdot C_6H_4\cdot N{:}N$$N(CH_3)_2$.

10 g. of sulphanilic acid (1 mol) (Exp. 127), dried in a steam oven, are dissolved in a solution of 3·1 g. of anhydrous

sodium carbonate ($\frac{1}{2}$ mol) in 100 ml. of water. The mixture is then treated with a solution of 4 g. of pure sodium nitrite (1 mol) in 20 ml. of water. The mixture is cooled, and gradually treated with a quantity of hydrochloric acid corresponding with 2·1 g. of the anhydrous acid (1 mol). For this purpose ordinary concentrated acid should be diluted with an equal volume of water, and the specific gravity of the mixture determined accurately at 15° by means of a hydrometer. The percentage strength of the diluted acid (by weight) is obtained by reference to a table of variation of specific gravity with strength of solution.

A solution of 7 g. of dimethylaniline, $C_6H_5N(CH_3)_2$, (1 mol), in the same amount of hydrochloric acid as indicated above (1 mol), diluted to 20 ml., is added to the mixture, and the liquid made alkaline by the addition of sodium hydroxide solution (excess should be avoided). Separation of methyl orange at once occurs; the quantity of product is increased by "salting out" (about 25 g. of finely powdered common salt is added to the solution, and stirred well until dissolved). The dye is filtered off, dried on a porous plate, and recrystallized from a little water. Yield nearly theoretical.

Helianthine is the sodium salt of the sulphonic acid, and the aqueous solution has a yellow colour. On the addition of mineral acid the free sulphonic acid is obtained, which has a red colour in aqueous solution. The use of the dye as an indicator in acidimetry and alkalimetry depends upon this change of colour.

Experiment 192.—"Coupling" of diazotized sulphanilic acid with β-naphthol: Orange II.

$$C_6H_4\begin{cases}SO_3Na\\N_2Cl\end{cases} + C_{10}H_7\cdot ONa \rightarrow C_6H_4\begin{cases}SO_3Na\\N{:}N\cdot C_{10}H_6\cdot OH\end{cases} + NaCl.$$

17·3 g. of dry sulphanilic acid are dissolved in a solution of the theoretical amount of anhydrous sodium carbonate in 500 ml. of water, the mixture cooled with cold water or ice, and 30 ml. of concentrated hydrochloric acid added; 100 ml. of a normal solution of sodium nitrite are then added slowly (apply the starch-potassium iodide paper test to determine the end of the reaction), and part of the diazonium compound settles out as fine crystalline needles.

14·4 g. of β-naphthol are dissolved in 100 ml. of normal sodium hydroxide solution, the mixture cooled well, and then

the diazonium solution prepared above is added gradually with constant stirring. When the addition is complete the solution should show a slightly alkaline reaction. The solution is allowed to stand overnight, common salt being added to facilitate the separation of the dye. The precipitate is filtered on a Buchner funnel at the pump, washed with a little water, and dried. Yield, 34 g., i.e. 75 per cent of theory.

It is a bright orange powder soluble in water, with an orange colour; it dyes wool orange from an acid bath.

Experiment 193.—"Coupling" of diazotized *p*-nitraniline with β-naphthol: Paranitraniline red.

A small amount of this can easily be prepared as a test-tube experiment by diazotizing a suspension of *p*-nitraniline in hydrochloric acid and adding this to a solution of β-naphthol in caustic soda. The dyestuff is insoluble in both dilute acids and alkalis and is usually developed on the fibre itself.

Substantive Dyes.

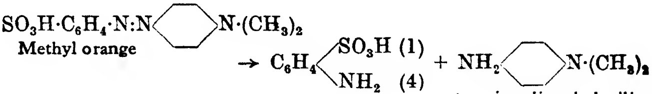
The two amino-groups in a compound of the type of benzidine, $p\text{-}NH_2{\cdot}C_6H_4{\cdot}C_6H_4{\cdot}NH_2\text{-}p$, can both be diazotized either in two distinct stages or simultaneously. In the latter case the tetrazonium salt is coupled with two molecules of the same amine or phenol and a *simple* benzidine dyestuff of the *congo red* type is formed. When diazotized in stages it is usual to couple with two different amines or phenols, when *mixed* benzidine dyes are obtained. Dyes of these types are of great commercial value and are termed substantive dyes, as they dye cotton fabrics direct, i.e. they require no mordant.

Experiment 194.—Congo red, $NH_2(SO_3H)C_{10}H_5{\cdot}N_2{\cdot}C_6H_4{\cdot}N_2{\cdot}C_{10}H_5(SO_3H)NH_2$, from benzidine and naphthionic acid (1·4·naphthylamine sulphonic acid).

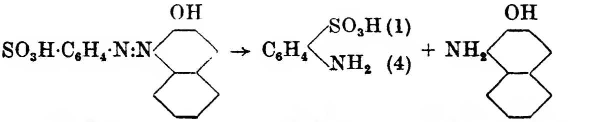
5 g. of benzidine are dissolved in 100 ml. of warm hydrochloric acid (1 conc. : 7 water). The solution is diluted to 250 ml., cooled by ice, and diazotized by the addition of 3·75 g. sodium nitrite in 20 ml. water, the operation taking 1–2 minutes. After standing for 5 minutes the diazotized solution is added with stirring to a solution of 18 g. sodium naphthionate and 20 g. sodium acetate in 250 ml. of water The blue-black precipitate (acid dye) is dissolved by the addition of sodium carbonate solution, filtered from impurities, and the sodium salt separated from the clear filtrate by the gradual addition of common salt. The red solid is removed by filtration and washed with brine.

For preparation of other azo-dyes, see Cain and Thorpe, *Synthetic Dye-stuffs*, or Saunders, *Aromatic Diazo-Compounds*.

Determination of the Constitution of an Azo-dye by Reduction.—Reducing agents such as zinc dust and water, tin and hydrochloric acid, or stannous chloride, split the azo-compounds at the point of union of the two nitrogen atoms of the azo-group, yielding (*a*) the base from which the azo-dye was derived, and (*b*) the amino-derivative of the substance with which it was " coupled ", the amino-group being in the position previously occupied by the azo-group, e.g.



Methyl orange　　Sulphanilic acid　　*p*-amino-dimethylaniline



Orange II　　Sulphanilic acid　　1-amino-β-naphthol

The best reducing solution * consists of 40 g. of stannous chloride dissolved in 100 ml. of pure hydrochloric acid (sp. gr. 1·19). 1 g. of the pure recrystallized dye dissolved in the least possible quantity of hot water is treated with 6 ml. of the reducing solution.† The reduction usually takes place immediately, frequently with violent ebullition, and the liquid rapidly becomes colourless. The subsequent method of procedure depends on the nature of the azo-compound reduced.

Experiment 195.—Reduction of helianthine.

5 g. of the pure dye are dissolved in the least possible quantity of boiling water to a clear solution (about 50 ml.), and treated with 30 ml. of a stannous chloride solution prepared as above, until decolorization takes place. The resulting solution is cooled and allowed to stand for some time, when sulphanilic acid (cf. Exp. 127) crystallizes out. This is filtered off, and the filtrate diluted with water and treated with sodium hydroxide solution until the precipitate at first formed is completely redissolved. It is then extracted several times with

* *Witt.*, B. 1888, **21**, 3471.

† Another method is to use a solution of 1·3 g. of tin in 7·5 ml. concentrated hydrochloric acid for each gram of dye.

ether, the ethereal solution dried with sticks of potash, and the ether removed. The residual oil solidifies on cooling and rubbing with a glass rod, and consists of crystals of *p*-aminodimethylaniline, m.p. 41°.

Experiment 196.—Determination of the constitution of Orange II, $\underset{4}{SO_3H}\cdot \underset{1}{C_6H_4}\cdot \underset{1}{N}:N\cdot C_{10}\underset{2}{H_6}\cdot OH$.*

20 g. of the dyestuff are dissolved in 200 ml. of water, and a hot solution of 26 g. of tin in 150 ml. of concentrated HCl is added. As the solution cools crystals of 1-amino-2-naphthol hydrochloride separate. These are removed, washed with dilute hydrochloric acid, dissolved in water containing a little sulphurous acid, and reprecipitated by the addition of concentrated hydrochloric acid. The second reduction product, sulphanilic acid, can be isolated from the mother liquor.

J. Reduction of Diazonium Salts

1. Replacement of the Diazo-Group by Hydrogen.

(i) Reduction by means of alkaline stannite solution.

Experiment 197.—Benzene from aniline.

5 g. of aniline are diazotized as described in Exp. 182. The diazonium solution is cooled in ice, and then treated gradually with excess of a strong alkaline stannite solution, prepared by dissolving 20 g. of stannous chloride in 50 ml. of water, and adding a strong solution of potassium hydroxide until the precipitate at first formed redissolves. When all the reducing solution has been added, the flask containing the mixture is attached to a condenser and the solution boiled, when benzene distils over. The product is dried with calcium chloride and redistilled. Yield, 3–4 g.; b.p. 81°.

(ii) Reduction by means of alcohol.

Experiment 198.—1:3:5-Tribromobenzene, $C_6H_3Br_3$, **from** ***sym*-tribromaniline.**†

50 g. of *s*-tribromaniline (Exp. 41) are pulverized and dissolved in about 300 ml. of hot rectified spirit mixed with 75 ml. of benzene in order to increase its solvent power. 20 ml. of conc. sulphuric acid are run in from a pipette, and if a precipitate forms this is redissolved by longer heating and, if necessary, by the addition of more of the solvents. 20 g.

* *Grandmougin* and *Michel*, B. 1892, **25**, 981.

† *Loring Jackson* and *Bentley*, Am. 1892, **14**, 335.

of finely powdered sodium nitrite are sifted into the hot liquid as rapidly as the violent reaction will allow, and the whole then heated until effervescence ceases. After standing overnight the precipitate is filtered, washed with hot water to remove the sodium sulphate, and dried. Yield 45 g., i.e. 95 per cent of theory. It crystallizes from alcohol in colourless prisms; m.p. 119°.

To make sure that it contains no unaltered tribromaniline, a small amount is dissolved in dry benzene, and dry hydrogen chloride is passed in. If a precipitate of tribromaniline hydrochloride is formed, the whole can be treated in the same manner and the precipitate filtered off. The clear filtrate when evaporated will yield pure tribromobenzene.

2. **Reduction of the Diazo-Group to the Hydrazo-Group in Acid Solution: Aromatic Hydrazines.** (S.B. Chap. XXII, D.)

$$C_6H_5{\cdot}N_2Cl + 2SnCl_2 + 4HCl \rightarrow C_6H_5{\cdot}NH{\cdot}NH_2, HCl + 2SnCl_4.$$

Experiment 199.—Phenylhydrazine, $C_6H_5{\cdot}NH{\cdot}NH_2$, **from aniline.**

10 g. of pure aniline are dissolved in a mixture of 30 g. of concentrated hydrochloric acid and 75 ml. of water, and diazotized in the usual manner (Exp. 182). The diazotized solution is saturated with common salt by adding 30 g. of finely powdered salt, shaking well, and decanting the liquid from any undissolved solid. An ice-cold solution of 60 g. of stannous chloride in 25 g. of concentrated hydrochloric acid is added, the mixture kept for several hours, and the precipitated phenylhydrazine hydrochloride filtered by means of a Buchner funnel. The hydrochloride is then decomposed with excess of sodium hydroxide solution; the phenylhydrazine separates as an oil and is taken up with ether, the ethereal solution dehydrated with anhydrous potassium carbonate, and the ether removed by distillation. The residue of phenylhydrazine is distilled under diminished pressure. Yield, 10 g.

It consists of crystalline plates; m.p. 23°; b.p. 120°, under 12 mm. pressure.

The hydrazines are basic substances and yield crystalline salts with acids. They condense with aldehydes, ketones, and their derivatives, with the formation of hydrazones (cf. Exps. 224, 225). In certain cases excess of the hydrazine acts as an oxidizing agent and osazones are formed (cf. Exp. 226), but as a rule the hydrazines possess strong reducing properties.

K. Estimation of the Diazo-Group in Aromatic Diazonium Salts and in Diazo-amino-Compounds.

A given weight of the substance is heated with sulphuric acid and the volume of nitrogen measured. Every gram molecule of nitrogen evolved corresponds with an N_2 group in the original molecule. A somewhat rough method is that described under the velocity of decomposition of diazonium

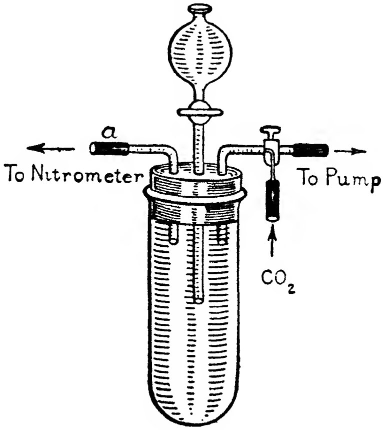


Fig. 87

salts (Chap. XXXVI, D). The mixture is heated, then allowed to cool, and the increase in the gaseous volume measured. A more accurate method * is to displace the air in the apparatus by carbon dioxide and to collect merely the nitrogen in some form of nitrometer. A stout glass tube, 10–12 cm. long and 3 cm. diameter. is fitted as shown in fig. 87. A weighed quantity of the diazo-compound is placed in the tube, the stem of the dropping funnel is drawn out to a fine point, and the stem and stopcock filled with freshly boiled water. The tube *a* is clamped and the apparatus evacuated by means of the water pump. Carbon dioxide is then led in through the three-way cock and the apparatus evacuated, and again filled with carbon dioxide. The operation is repeated. and then all the air

* *Mehner*, J. pr. 1901, [ii], 63, 305.

will have been removed with the exception of the small amount in the rubber tube *a*. This is got rid of by opening the clamp and passing a stream of carbon dioxide through the apparatus. *a* is then attached to a nitrometer or eudiometer over potash, and the gas tested to make sure that it is free from air. Concentrated hydrochloric acid is run in from the dropping funnel until the tube is about one-fifth full. The contents are rapidly heated to boiling, and then the gas left driven over by allowing water to enter from the funnel, and finally by passing a current of carbon dioxide.

XXI. ALDEHYDES AND KETONES
(S.B. Chaps. V and XXV)

A. Aldehydes, $R\cdot C\begin{matrix}\nearrow O\\ \searrow H\end{matrix}$

1. Modes of Formation.

Method 1.—By the regulated oxidation of primary alcohols.

$$R\cdot CH_2OH + O \rightarrow R\cdot C\begin{matrix}\nearrow O\\ \searrow H.\end{matrix}$$

(*N.B.*—Secondary and tertiary alcohols do not yield aldehydes on oxidation.)

It is necessary to regulate the amount of oxidizing material somewhat carefully, as the aldehydes themselves are readily oxidized to carboxylic acids.

$$R\cdot C\begin{matrix}\nearrow O\\ \searrow H\end{matrix} + O \rightarrow R\cdot COOH.$$

Experiment 200.—Acetaldehyde from ethyl alcohol.

The reactions involved and the reacting proportions are represented in the following equations:

$$Na_2Cr_2O_7 + 5H_2SO_4 \rightarrow 2NaHSO_4 + Cr_2(SO_4)_3 + 4H_2O + 3O$$
$$3CH_3\cdot CH_2\cdot OH + 3O \rightarrow 3CH_3\cdot CHO + 3H_2O.$$

To avoid further oxidation of the aldehyde an excess of the alcohol is used.

A round-bottomed flask of $1\frac{1}{2}$ litre capacity, containing a mixture of 120 g. of concentrated sulphuric acid and 200 g. of water, is fitted with a cork carrying a dropping funnel and a delivery tube connected with a long condenser. The end of the condenser tube is fitted with an adapter which leads into a receiver surrounded by a freezing mixture of ice and salt.

When the contents of the flask have been heated just to boiling, a mixture of a solution of 200 g. of sodium dichromate in 200 g. of water and 120 g. of alcohol (rectified spirit) is added gradually through the tap funnel. Generally the heat developed by the reaction is sufficient to keep the liquid boiling without the aid of external heat, but if this is not so, ebullition is assisted by applying a small flame. The aldehyde formed during the reaction distils over into the receiver, mixed with some water, alcohol, and acetal. Care is taken that the reaction does not proceed too violently, as the aldehyde is extremely volatile, and a portion of the reaction product will then be lost. After all the alcohol-bichromate mixture has been added the flask is heated for a short time on a sand tray, in order to drive over the remaining product. Altogether some 150 ml. of distillate are collected.

The aldehyde cannot be separated completely from the distillate by fractional distillation, and is therefore purified by conversion into a crystalline derivative, viz. aldehyde-ammonia ($CH_3 \cdot CHO, NH_3$). From this the aldehyde can be regenerated by treatment with an acid.

For the preparation of aldehyde-ammonia the apparatus shown in fig. 88 is employed. The flask containing the distillate is attached to a sloping condenser (N.B. *Do not use rubber stoppers*) filled with water at a temperature of 30–35°. A tube leads from the condenser to the absorption vessels; these contain 50 ml. of dry ether (Exp. 29), and are cooled by ice. The contents of the flask are heated to boiling; alcohol and aqueous vapour condense in the condenser tube, while the aldehyde passes on and is absorbed by the ether.

The ethereal solution of aldehyde is now saturated with dry ammonia (prepared by gently heating some concentrated (0·880) ammonia solution, and leading the evolved gas through a lime tower), care being taken that a *wide* tube is used. Aldehyde-ammonia separates in the form of colourless crystals, and after standing for a short time the clear liquid is decanted

from the crystals, which are filtered with the aid of the pump, washed with a little dry ether, and finally dried in a desiccator. Yield of aldehyde-ammonia about 30 g.

To prepare pure aldehyde, a portion of the aldehyde-ammonia is dissolved in an equal weight of water, and dis-

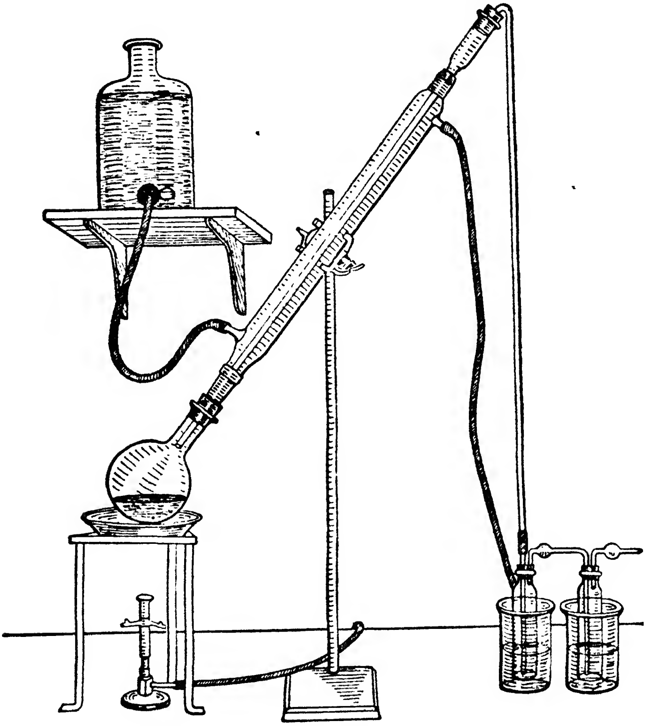


Fig. 88

tilled in a small distilling flask with a mixture of $1\frac{1}{2}$ parts of concentrated sulphuric acid and 2 parts of water. The receiver is well cooled in a freezing mixture of ice and salt. To dehydrate the product it is redistilled over an equal bulk of granular calcium chloride. The pure aldehyde is a colourless liquid with a characteristic odour; b.p. 21°; $D^{0°}_{4°}$, 0·807; it is miscible in all proportions with water, alcohol, and ether.

Methyl alcohol can be readily oxidized to formaldehyde by passing a stream of air saturated with the vapour of the alcohol over certain metals (e.g. spongy platinum). Copper in the form of a brightly polished wire spiral or a reduced copper gauze, as used in a combustion furnace, works well, but must be heated in order to start the reaction.

Experiment 201.—Formaldehyde from methyl alcohol.

$$HCH_2OH + O \rightarrow HCHO + H_2O.$$

The side tube of a 250 ml. distilling flask is drawn to a capillary and led into a length of combustion tubing about 30

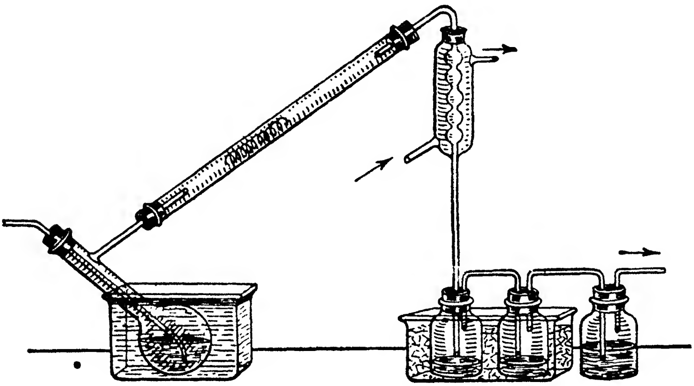


Fig 89.

cm. long which contains a close wound spiral of copper wire or a reduced copper gauze of 5–6 cm. length (fig. 89). This leads further to an efficient condensing system consisting of a double surface condenser and a train of absorption bottles, three in number, two being originally empty and immersed in a bath of ice and salt (or, better, CO_2 snow), and the last containing a little water. The exit tube of the latter is connected to a water pump. The mouth of the distilling flask is fitted with cork and inlet tube leading to the bottom of the flask, and the flask is immersed in a large water bath. The whole is arranged so that the combustion tube has an upward slope of about 30 degrees.

100 ml. of methyl alcohol are placed in the distilling flask and the bath heated up to and kept at a temperature of 46–

47°. The pump is started and a slow current of air drawn through the system. The copper spiral is then heated by means of a small burner until the reaction starts, after which the oxidation can be controlled by means of the suction pump. The capillary end of the side tube prevents an explosion striking back into the flask. The product obtained in the collecting vessels consists of a mixture of formaldehyde, methyl alcohol and water. The aldehyde content of the solution may be determined by the iodine-potassium bisulphite method (Chap. XXXV, N).

Tests for Formaldehyde.

(i) A very dilute solution of formaldehyde gives a purple colour with a drop of concentrated sulphuric acid and a speck of morphine (cf. test for methyl alcohol, p. 120).

(ii) 10 ml. of the solution prepared in Exp. 201 are treated with excess of ammonia solution and evaporated to dryness in a dish on a water bath. Colourless crystals of hexamethylene tetramine $(CH_2)_6N_4$ are obtained which sublime unchanged on heating.

(iii) Heated with a little β-naphthol and a few drops of concentrated hydrochloric acid, a solution of formaldehyde yields colourless crystals of methylene-di-β-naphthol, m.p. 189–192° (dec.). This product is also given by the polymers.

(iv) *Dimedone test.* 0·1 g. of dimedone is dissolved in 5 ml. of 50 per cent alcohol and a drop of formaldehyde (or an appropriate volume of the liquid to be tested) added. The solution is warmed and allowed to stand till cool. The derivative separates as fine, colourless crystals, m.p. 189°*

Method II.—Heating a mixture of the calcium salt of the corresponding monobasic acid with calcium formate, e.g.

$$CH_3COOca + HCOOca = CaCO_3 + CH_3{\cdot}CH{:}O \quad [ca = \tfrac{1}{2}Ca]$$

Experiment 202.—Acetaldehyde from calcium acetate and calcium formate.

Equal quantities of the two salts are well mixed and heated in a hard glass test tube. Acetaldehyde is evolved, which is detected by its odour. It is tested further by passing into Schiff's reagent (Exp. 208).

The product obtained by this method contains several impurities.

* Org. Reagents for org. analysis, *Hopkin and Williams*, London, 1944.

Method III.—By the hydrolysis of dihalogen substitution products of the hydrocarbons, in which the two halogen atoms are attached to the same terminal carbon atom, by superheating with water or boiling with milk of lime or calcium carbonate, e.g.

$$\underset{\text{Benzal chloride}}{C_6H_5CHCl_2} \rightarrow C_6H_5CH(OH)_2 \rightarrow \underset{\text{Benzaldehyde}}{C_6H_5CH{:}O} + H_2O.$$

In many cases they may be obtained from the corresponding monohalogen derivatives by a combined process of hydrolysis and oxidation. Cupric or plumbous nitrate is generally used for this purpose.

Experiment 203.—Benzaldehyde, $C_6H_5{\cdot}CH{:}O$, **from benzyl chloride.**

$$C_6H_5{\cdot}CH_2Cl \rightarrow C_6H_5{\cdot}CH_2{\cdot}OH \xrightarrow{+O} C_6H_5{\cdot}CH{:}O.$$

25 g. of benzyl chloride (Exp. 38) are heated with a solution of 40 g. of plumbous nitrate in 250 ml. of water in a reflux apparatus, until a test portion of the oily layer, after washing well with water, no longer gives the reaction for halogens (p. 41); about five to six hours boiling will be necessary. Half the liquid is then distilled off, the benzaldehyde passing over with the steam and separating as an oil. The distillate is mixed with a concentrated solution of sodium bisulphite until after prolonged shaking the greater part of the oil has gone into solution. The additive compound of benzaldehyde with sodium bisulphite is formed; should crystals separate out, water is added until they are again dissolved. The solution is then separated from any oil remaining undissolved, and treated with solid sodium carbonate until it shows a strongly alkaline reaction. The mixture is then distilled with steam (fig. 10), and pure benzaldehyde which passes over is taken up with ether. The ethereal solution is dried, and after removal of the solvent the residue is distilled. Yield, 15 g.

Benzaldehyde is a colourless highly refractive liquid, with a pleasant bitter-almond odour; it is sparingly soluble in water, but dissolves readily in alcohol and ether. B.p. 179°; $D_{4°}^{15°}$, 1·050.

*Method IV.—Etard's reaction.** (S.B. Chap. XXV, B.)

Aromatic aldehydes may be prepared directly from methyl

* *Bornemann*, B. 1884, 17, 1462.

derivatives of benzene. An additive compound of the hydrocarbon with chromyl chloride is first prepared, which is subsequently decomposed with water.

$$C_6H_5{\cdot}CH_3 + 2CrO_2Cl_2 = C_6H_5CH_3, (CrO_2Cl_2)_2$$
$$3C_6H_5CH_3(CrO_2Cl_2)_2 + 3H_2O$$
$$= 3C_6H_5{\cdot}CHO + 4CrCl_3 + 2H_2CrO_4 + 4H_2O.$$

Experiment 204.—*p*-Nitrobenzaldehyde from *p*-nitrotoluene.* 10 g. of *p*-nitrotoluene (1 mol) and 25 g. of chromyl chloride † (less than 2 mols) are separately dissolved in dry carbon disulphide to 15 per cent solutions. The toluene solution is placed in a 500 ml. flask fitted with a long reflux condenser, and the solution of chromyl chloride added gradually in quantities of from 10 to 15 ml. at a time. Should no reaction occur at the first addition of chromyl chloride solution, the mixture is allowed to stand for some time before further addition. Great heat is developed during the reaction, and the flask should be cooled by immersing in a bath of cold water. Under no condition should the temperature of the mixture rise above 47°. When all the reagent has been added, the mixture is allowed to stand for two days. The double compound, which separates as a dark-coloured precipitate, is removed by means of a Buchner funnel and the pump, washed well with small amounts of dry carbon disulphide, and when dry is decomposed by adding, little by little, to excess of cold water contained in a large beaker. The mixture is heated to remove traces of carbon disulphide and is then digested with dilute sodium carbonate solution to remove *p*-nitrobenzoic acid and finally crystallized from hot water. It consists of long prisms, m.p. 107°. Yield about 90 per cent of theory.

Method V. — Tiemann-Reimer Synthesis.‡ (S.B. Chap. XXV, D).

Hydroxy-aldehydes of the aromatic series are readily obtained from phenols by this method, which consists in condensing the phenol with chloroform in the presence of concentrated sodium hydroxide solution. A dichloro-derivative is

* As there is a possibility that the reaction may become very vigorous and the carbon disulphide boil over, it is advisable to carry out the preparation in a room in which flames are not allowed.

† For preparation, see Chap. XXXVIII.

‡ *Reimer* and *Tiemann*, B. 1876, 9, 423, 824.

probably first formed, but is immediately hydrolysed to the aldehyde (cf. Method III).

$$OH{\cdot}C_6H_4{\cdot}\boxed{H + Cl}{\cdot}CHCl_2 \rightarrow OH\,C_6H_4{\cdot}CHCl_2 + HCl$$
$$OH{\cdot}C_6H_4{\cdot}CHCl_2 + H_2O \rightarrow OH{\cdot}C_6H_4{\cdot}CHO + 2HCl.$$

The aldehydic group introduced takes up the *ortho-* and to some extent the *para*-position with respect to the hydroxyl group.

Experiment 205.—Salicylaldehyde, $C_6H_4(OH){\cdot}CHO$, **from phenol and chloroform.**

40 g. of phenol are treated with a solution of 40 g. of sodium hydroxide in 120 ml. of water in a litre flask fitted with a reflux condenser. The mixture is heated to a temperature of 50–60° by immersion in a hot-water bath, while 60 g. of chloroform are added gradually in small portions of 10 ml. At the beginning of the operation the yellow-coloured liquid changes to violet, and later assumes a deep-red colour. After each addition of chloroform the flask is well shaken, and when all has been added the contents are boiled for half an hour to complete the reaction.

The excess of chloroform is then removed by heating on a water bath, and the residue is acidified with dilute hydrochloric or sulphuric acid. A thick red oil separates; this is steam-distilled (fig. 10), the distillation being continued as long as oily drops pass over. The yellow oily distillate contains phenol and salicylic acid in addition to salicylaldehyde. It is extracted with ether, and the ethereal solution shaken up with a nearly saturated solution of sodium bisulphite (freshly prepared). The bisulphite additive compound (cf. Exp. 209) separates in the form of fine crystals, which are filtered off and decomposed by heating with dilute acid. The product is extracted with ether, the ethereal solution washed with water and dried over calcium chloride. The ether is removed and the aldehyde distilled. It is a colourless oil with a pleasant odour. B.p. 196°; $D^{15°}$, 1·172. Yield, 8–10 g.

The mixture left in the flask after the steam distillation contains a small quantity of *p*-hydroxy-benzaldehyde, which is not volatile with steam. The mixture, which consists of a reddish-yellow liquid and a dark-red resinous substance, is filtered while still hot through a fluted filter, and the filtrate when cold extracted with ether. The ethereal extract is dried over calcium chloride and the solvent removed. The residue

is recrystallized from a little hot water, and forms colourless crystals, m.p. 116°. Yield about 2 g.

One of the cheapest aldehydes is furfuraldehyde (S.B. Chap. XL), which is obtained commercially by boiling corncobs or bran with dilute sulphuric acid (1 : 5), but the method is difficult to work on the small scale.

2. Chemical Characteristics of Aldehydes.

(*a*) The aldehydes show considerable chemical reactivity; thus, they are readily oxidized to the corresponding acids, e.g.

$$CH_3{\cdot}CH{:}O + O \rightarrow CH_3{\cdot}CO{\cdot}OH.$$

Consequently, they are good reducing agents, e.g. they reduce alkaline solutions of silver salts and often alkaline cupric solutions (Fehling's solution, p. 372).

Experiment 206.—Prepare an ammoniacal silver solution by taking 2 ml. of dilute silver nitrate solution in a *clean* test tube, and adding dilute ammonia solution drop by drop, until the precipitate at first formed just redissolves. (Excess of ammonia must be avoided.) Then add a few drops of acetaldehyde (or benzaldehyde), and after shaking allow to stand. Reduction takes place to metallic silver, which is deposited as a silver mirror on the sides of the tube. If the latter is not thoroughly clean, a black precipitate of the metal results.

Filter the solution, and test it for an acetate (or benzoate).

Experiment 207.—A few drops of acetaldehyde are added to a little Fehling's solution and warmed gradually. A reddish-yellow precipitate of cuprous oxide results.

Aromatic aldehydes do not give this reduction.

(*b*) A general reaction of aldehydes is their behaviour towards Schiff's reagent (a dilute solution of fuchsine (magenta) decolorized by sulphurous acid).

Experiment 208.—A few drops of an aldehyde are added to about 5 ml. of Schiff's reagent and the mixture well shaken. The red colour of the dye is restored.

Additive Reactions.

(*c*) Aldehydes form additive compounds with many reagents.

1. Compounds with ammonia—aldehyde ammonias.

An example has been given in the preparation of acetaldehyde (Exp. 200). The compounds are generally crystalline substances which are soluble in water but insoluble in ether. Treated with acids, they regenerate the aldehyde. Benzalde-

hyde and other aromatic aldehydes do not form simple additive compounds with ammonia, but yield complex condensation products (cf. also Ketones, this Chap., B).

2. Aldehydes yield crystalline additive compounds with sodium bisulphite, $NaHSO_3$. Formerly the additive compounds were regarded as the sodium salts of sulphonic acids, e.g. $CH_3{\cdot}CH\langle^{OH}_{SO_3Na}$, but the readiness with which they are hydrolysed has led chemists to regard them as containing the S atom attached to oxygen and not directly to carbon, e.g. $CH_3{\cdot}CH\langle^{OH}_{O{\cdot}SO{\cdot}ONa}$. See Chap. XVI, B, II.

Experiment 209.—Make a fresh, almost saturated, solution of sodium bisulphite in distilled water, and to about 5 ml. of the solution add 1 ml. of benzaldehyde, and shake vigorously. A white crystalline additive compound separates. Filter off the crystals, and treat them with dilute acid; the aldehyde is regenerated.

The bisulphite compounds, like the aldehyde-ammonias, are largely employed in the separation of aldehydes from mixtures (cf. Exps. 203, 205).

3. The aldehydes also yield additive compounds with hydrogen cyanide, e.g.

$$C_6H_5{\cdot}CH{:}O + HCN = \underset{\text{Mandelic nitrile}}{C_6H_5{\cdot}CH\langle^{OH}_{CN}}.$$

(Cf. Exp. 321.)

(*d*) **Polymerization of Aldehydes.**—The aldehydes show a great tendency to polymerize.

1. Formation of paracetaldehyde and metacetaldehyde.

Experiment 210.—A few drops of concentrated sulphuric acid are added to about 1 ml. of acetaldehyde. The mixture becomes hot, and on the addition of water an oil (paraldehyde, $(C_2H_4O)_3$, b.p. 124°) separates. If the temperature is kept below 0° the product is mainly metacetaldehyde (a solid) with some paracetaldehyde.

2. At temperatures below −12° in the presence of aqueous potassium cyanide acetaldehyde dimerizes to aldol (so-called aldol condensation),

$$CH_3{\cdot}CH{:}O + CH_3{\cdot}CH{:}O \rightarrow CH_3{\cdot}CH(OH){\cdot}CH_2{\cdot}CH{:}O,$$

which readily loses water, giving crotonaldehyde, $CH_3 \cdot CH:CH \cdot CHO$.

3. An alcoholic solution of potassium cyanide causes the dimerization of aromatic aldehydes of the type of benzaldehyde with the production of a hydroxy-ketone (so-called benzoin condensation): *

$$C_6H_5CHO + O:CH \cdot C_6H_5 \rightarrow C_6H_5 \cdot CH(OH) \cdot CO \cdot C_6H_5.$$

Experiment 211.—Benzoin, $C_6H_5 \cdot CH(OH) \cdot CO \cdot C_6H_5$, **from benzaldehyde.**†

20 g. of pure benzaldehyde and a solution of 2 g. of pure potassium cyanide (94–100 per cent) in 80 ml. of 50 per cent alcohol are heated in a reflux apparatus for an hour on a water bath. On allowing to cool, crystals of benzoin separate. These are filtered off, and the filtrate is again heated with another quantity of potassium cyanide; on cooling, a second yield of crystals is obtained. The product is recrystallized from hot alcohol and obtained in the form of colourless needles, m.p. 137°. Yield, 90–95 per cent of theory.

It contains both a secondary alcohol grouping (cf. Chap. X) and a ketonic grouping (cf. Chap. XXI, B). It is readily oxidized to the α-diketone, benzil (Exp. 278), and yields condensation products with hydroxylamine, &c. (cf. Chap. XXII, B).

(*e*) **Action of Alkalis on Aldehydes.**

Various aldehydes behave differently towards alkalis. Acetaldehyde and several of its homologues are transformed into a reddish-brown aldehyde-resin, a substance insoluble in water but soluble in alcohol. The majority of the aliphatic aldehydes undergo the aldol dimerization (S.B. Chap. V). The aromatic aldehydes are transformed by alkalis into a mixture of equivalent amounts of the corresponding alcohol and acid (see Exp. 25).

The reactivity of the aldehydes is analogous to the reactivity of the olefines (Chap. IX, B), e.g. both are readily oxidized, both can be reduced, both form additive compounds, and both polymerize readily. This similarity in chemical properties is due to a similarity in chemical constitution. The olefines contain a double bond between two carbon atoms,

* *Nef*, A. 1895, **287**, 342; 1897, **298**, 312.

† *Zinin*, A. 1840, **34**, 187; *Zincke*, A. 1879, **198**, 150, footnote.

and the aldehydes a double bond between a carbon and an oxygen atom.

$$CH_3{\cdot}CH{:}CH_2 \text{ and } CH_3{\cdot}CH{:}O.$$

B. Ketones (R·CO·R or R·CO·R′)

Modes of Formation.

Method I.—By the distillation of the dry calcium or barium salts of monobasic acids.

$$\begin{matrix} R{\cdot}COO \\ R{\cdot}COO \end{matrix}\!\!>\!Ca = CaCO_3 + R{\cdot}CO{\cdot}R.$$

Experiment 212.—Acetone, $CH_3{\cdot}CO{\cdot}CH_3$, from calcium acetate.

100 g. of dried calcium acetate are heated, by means of a large luminous flame kept in constant motion, in a retort attached to a long condenser. The distillate, which contains some tarry matter, is treated with an equal volume of water which dissolves the acetone, and then filtered through a fluted filter paper to remove insoluble matter. The filtrate is allowed to stand for several hours over lumps of quicklime in a flask attached to a reflux condenser, and the acetone is then distilled off. It is further dried by standing over calcium chloride, and forms a colourless liquid with a peculiar odour; b.p. 56°; $D^{0°}$, 0·81. It is soluble in water, but may be salted out from its aqueous solutions, and is miscible in all proportions with alcohol and ether.

Special Tests for Acetone.

1. Acetone gives the iodoform reaction (cf. Exp. 53).
2. A solution of acetone in sodium hydroxide gives a blue coloration of indigo when warmed with *o*-nitro-benzaldehyde.

Method II.—Friedel and Crafts' Synthesis. (S.B. Chap. XVIII.)

Friedel and Crafts' general reaction consists in condensing a benzene hydrocarbon with an alkyl or acyl halide in the presence of anhydrous aluminium chloride, hydrogen halide being evolved.

$$C_6H_5\boxed{H + Cl}{\cdot}R = HCl + C_6H_5{\cdot}R.$$

The reaction is useful for the preparation of hydrocarbons,

especially of the triphenyl-methane series (Exp. 305*a*). When an acyl chloride is used, the product is a ketone, e.g.

$$C_6H_5\boxed{H + Cl}\cdot CO\cdot CH_3 = HCl + C_6H_5\cdot CO\cdot CH_3.$$

The aluminium chloride first forms an additive compound with the acyl chloride (e.g. $CH_3\cdot COCl, AlCl_3$), which then reacts with the hydrocarbon, producing hydrogen chloride and a compound, e.g. $C_6H_5\cdot CO\cdot CH_3$, $AlCl_3$, and this, when decomposed by water, yields the ketone.

Since the reaction takes place vigorously, it is advisable to dilute the reacting substances by solution in a suitable solvent. Generally carbon disulphide is used, but large excess of the reacting hydrocarbon may often be employed.

Experiment 213.—Benzophenone, $(C_6H_5)_2C{:}O$, **from benzene and benzoyl chloride.**

20 g. of freshly prepared and finely divided aluminium chloride (Chap. XXXVIII) are added gradually to a mixture of pure benzene (20 g.), benzoyl chloride (20 g.) (Exp. 35), and carbon disulphide (100 g.), contained in a round-bottomed flask attached to a reflux condenser. The flask is shaken during the addition of the metallic chloride, and is afterwards heated gently on a water or steam bath (no flame) until hydrogen chloride is no longer evolved (2–3 hours). The carbon disulphide is then distilled off (see Precautions), the residue cooled and then poured gradually into ice-cold water. Concentrated hydrochloric acid (about 7 ml.) is added, and the whole is steam-distilled in order to remove any residual benzene. After cooling, the contents of the flask are extracted with ether, the ethereal extract washed with diluted alkali, then with water, dried and fractionally distilled. Benzophenone, which distils at 297°, solidifies on cooling to a crystalline mass, m.p. 48°; yield, 20 g.

Experiment 214.—Acetophenone, $C_6H_5\cdot CO\cdot CH_3$, **from benzene and acetyl chloride.**

The procedure is exactly as in Exp. 213, using an equivalent amount of acetyl chloride (or even better, acetic anhydride) instead of benzoyl chloride. Acetophenone has m.p. 20·5°; b.p. 202°.

Experiment 215.—*p*-Methoxy-benzophenone, $C_6H_5\cdot CO\cdot C_6H_4\cdot OCH_3$, **from anisole,** $C_6H_5\cdot OCH_3$, **and benzoyl chloride.***

* *Gattermann, Ehrhardt* and *Maisch*, B. 1890, 1204.

A mixture of 10·8 g. anisole, 13 g. benzoyl chloride and 25 g. carbon disulphide is treated with 10 g. of aluminium chloride, as above. The mixture is heated on the water bath until hydrogen chloride ceases to be evolved (3–4 hours), the carbon disulphide removed as above, and the product treated with cold water. The product generally solidifies and may be filtered off. If oily, it is taken up with ether and the solution treated as in Exp. 213. It is recrystallized from a little dry ether and consists of compact white crystals, m.p. 62°; yield, 15 g.

When several alkyl groups are present in the nucleus it is quite easy to introduce two acetyl groups, e.g. *s*-trimethylbenzene (mesitylene) readily yields the diketone, $C_6HMe_3(COMe)_2$, m.p. 46°, when the temperature is not raised.

The anhydrides of dibasic acids, e.g. phthalic anhydride and succinic anhydride, can be used in place of the acyl chlorides.

The products from phthalic anhydride contain acyl attached to the ring usually in the ortho-position to the carboxylic group.

Experiment 216.—*o*-Benzoylbenzoic acid from phthalic anhydride and benzene.*

$$C_6H_4\left\langle\begin{matrix}CO\\CO\end{matrix}\right\rangle O + C_6H_6 \rightarrow o\text{-}C_6H_4\left\langle\begin{matrix}CO\cdot OH\\CO\cdot C_6H_5\end{matrix}\right.$$

100 g. of sublimed aluminium chloride are added to 50 g. phthalic anhydride and 175 g. benzene and the mixture is stirred mechanically. The anhydride dissolves and hydrogen chloride is evolved. After two hours the temperature is raised very gradually by heating in an oil bath so that after 9 hours a temperature of 75° is reached. Water is added very gradually and the benzene then removed by steam distillation. The aqueous layer is poured off, the solid residue treated with excess of sodium carbonate solution, and the whole steamed for 4–5 hours. The precipitate of aluminium hydroxide is filtered off and the *o*-benzoylbenzoic acid precipitated from the filtrate by the addition of hydrochloric acid. After drying and recrystallizing from chloroform it melts at 127°.

Compounds of this type are of great interest, as by ring closure and elimination of water under the influence of sulphuric acid they yield anthraquinones (cf. Chap. XXXI).

General Chemical Characteristics of Ketones.

(*a*) *Oxidation.*—The ketones are not oxidized as readily as

* *Heller* and *Schulke*, B. 1908, 3627.

the aldehydes, and do not reduce alkaline silver and cupric solutions. Oxidizing agents, such as potassium bichromate and dilute sulphuric acid, slowly convert them into acids or ketones possessing a smaller number of carbon atoms to the molecule.

Experiment 217.—Boil 5 ml. of acetone for about an hour in a reflux apparatus with dilute sulphuric acid and potassium bichromate solution. Distil the product and test the distillate for acetic acid (Table X, p. 413).

$$CH_3{\cdot}CO{\cdot}CH_3 + 4O \rightarrow CH_3CO{\cdot}OH + CO_2 + H_2O.$$

Only a few ketones restore the colour to Schiff's reagent.

(*b*) *Additive Reactions.*—When reduced they add on hydrogen and yield secondary alcohols.

The ketones do not yield crystalline compounds with ammonia of the type of aldehyde-ammonia. The reaction is more complicated, two or more molecules of the ketone combining with one of ammonia, with elimination of water.

The simpler ketones, e.g. dimethyl ketone and methyl-ethyl ketone, yield crystalline compounds with sodium bisulphite (cf. Aldehydes).

Experiment 218.—Shake about 1 ml. of acetone with 5 ml. of a nearly saturated solution of sodium bisulphite. A crystalline derivative settles out. Filter off and warm the crystalline compound with dilute sodium carbonate solution. Acetone is regenerated, and can be detected by its odour.

Ketones in which the carbonyl group is directly attached to a benzene ring (e.g. acetophenone) do not yield bisulphite compounds, but form additive derivatives with hydrogen cyanide.

Just as certain aldehydes can undergo the aldol dimerization (condensation), simple ketones can also dimerize under the influence of solid barium hydroxide. Thus acetone condenses to diacetone alcohol.

$$CH_3{\cdot}CO{\cdot}CH_3 + CH_3{\cdot}CO{\cdot}CH_3 \rightarrow CH_3{\cdot}C(CH_3)(OH){\cdot}CH_2{\cdot}CO{\cdot}CH_3.$$

Experiment 219.—2-Methyl-2-hydroxypentan-4-one (diacetone alcohol) from acetone.

Acetone is boiled in a flask fitted with a long condenser and Soxhlet extractor (fig. 18). The extractor contains two extraction thimbles filled with crystalline barium hydroxide and loosely plugged with glass wool. The flask is heated on a

boiling-water bath until acetone no longer condenses in the tube—this may take several days. The contents of the flask are then distilled—using an efficient column—until all acetone is removed and the residue distilled under reduced pressure. B.p. 71–74° under 23 mm. pressure.

Ketones undergo many important condensations and thus yield a great variety of products (Chaps. XXII and XXVIII).

C. Recognition of Aldehydes and Ketones

1. The majority of aldehydes and ketones are colourless liquids; a few only are solid. The less complex members are soluble in water, and all dissolve in alcohol and ether. All the aldehydes and the ketones with the exception of the more complex ones dissolve in sodium bisulphite solution (cf. Exp. 209), and if the solution is concentrated, crystals of the additive compound are deposited after some time.

2. **Colour Test for both Aldehydes and Ketones.**

A few ml. of an aqueous or alcoholic solution of a ketone or aldehyde mixed with a few drops of a 10 per cent aqueous solution of *m*-phenylenediamine hydrochloride produce in the course of a few minutes a bright-green fluorescence, which reaches its maximum intensity at the end of two hours. The coloration is destroyed by free alkalis.

All aldehydes give the coloration, but mixed ketones and ketonic acids do not.

3. **Tollens' Aldehyde Test.***

Two separate solutions are prepared, the one containing 3 g. of silver nitrate in 30 ml. of water, and the other 3 g. of sodium hydroxide in 30 ml. of water. These can be bottled and used when required. In making the test, equal volumes of the two solutions are mixed in a *perfectly clean* test tube; ammonia solution (sp. gr. 0·923) is added drop by drop until the precipitate of silver oxide just dissolves. The addition of this ammoniacal solution to a dilute aldehyde solution produces a silver mirror in the cold (cf. Exps. 206, 207).

N.B.—*Do not heat the solution, as explosive fulminates are then formed.*

4. **Schiff's Reagent** (Exp. 208).

Most aldehydes restore the colour to a magenta solution

* B. 1881, **14**, 1950; 1882, **15**, 1635, 1828.

which has been decolorized by sulphurous acid. A few ketones give the same reaction when present in large quantities.

Both aldehydes and ketones condense with a number of different reagents yielding crystalline derivatives with definite melting-points (Chap. XXII and Tables XI and XII).

Further Reactions for Specific Aldehydes and Ketones.

Formaldehyde.—Cf. p. 256.

All the aldehydes are readily oxidized by alkaline permanganate to the corresponding acids, and the melting-points of these can be determined.

Acetone.—Cf. p. 263.

D. Estimation of the Carbonyl Group *

1. **With Phenylhydrazine.**—A given weight of the carbonyl compound is mixed with an excess of dilute aqueous phenylhydrazine solution † and kept for some time, after which an excess of 0·1 N. iodine potassium iodide solution is added. The iodine reacts with the free phenylhydrazine, but not with the hydrazone, according to the equation:

$$C_6H_5NH{\cdot}NH_2 + 2I_2 \rightarrow 3HI + N_2 + C_6H_5I.$$

The excess of iodine can then be titrated with standard sulphurous acid, using starch as indicator.

2. **With Hydroxylamine.**—The carbonyl group can also be estimated by means of hydroxylamine. Free hydroxylamine is prepared just before use by adding an equivalent of barium hydroxide solution to hydroxylamine sulphate. 0·1 N. solutions of the carbonyl derivative and of hydroxylamine in 50 per cent alcohol are used, and after the oxime formation is completed the excess of hydroxylamine is titrated with standard acid, using methyl orange as indicator.

3. **With Bisulphite and Iodine.**—The method given in Chap. XXXV, H, can be used for simple aldehydes.

* *E. v. Meyer*, J. pr. 1887 [2], **36**, 115.

† The base must be pure.

XXII. CONDENSATION DERIVATIVES OF ALDEHYDES AND KETONES

The aldehydes and ketones are extremely reactive, and enter into a large number of condensations, especially with compounds containing two atoms of hydrogen attached to a carbon or nitrogen atom. These products are of great use in identifying the aldehydes and ketones from which they are derived.

A. Anils or Schiff's Bases

Condensation with Primary Amines.

Aromatic aldehydes condense readily with primary amines with the production of Schiff's bases (S.B. Chap. XXI), e.g.

$$C_6H_5CHO + H_2NC_6H_5 = H_2O + C_6H_5CH{:}NC_6H_5.$$

Ketones condense similarly but with greater difficulty, a dehydrating agent, e.g. anhydrous zinc chloride, being required to promote the reaction.

Experiment 220.—Benzylidene-aniline, $C_6H_5{\cdot}CH{:}NC_6H_5$, from aniline and benzaldehyde.

Equivalent proportions of benzaldehyde and aniline are warmed together in a dish on a water bath with continual stirring. The solid product is dried on a filter pump and on porous plate and recrystallized from carbon disulphide (see Precautions).

Benzylidene-aniline consists of yellow needles, m.p. 54°, b.p. 300°, insoluble in water, readily soluble in alcohol and ether.

B. Condensation with Hydroxylamine; Formation of Oximes *

$$\begin{matrix}R\\R\end{matrix}\!\!>C{:}O + H_2N{\cdot}OH \rightarrow \begin{matrix}R\\R\end{matrix}\!\!>C{:}N{\cdot}OH + H_2O.$$

The carbonyl group in both aldehydes and ketones readily condenses with hydroxylamine, with the formation of aldoximes and ketoximes respectively. The reagent is generally used in the form of its hydrochloride, $HO{\cdot}NH_2$, HCl. The free base is usually liberated by the addition of the theoretical

* *V. Meyer* and *Janny*, B. 1882, 15, 1324.

amount of potassium hydroxide. The conditions best adapted for the preparation of an oxime vary with the specific aldehyde or ketone; sometimes the hydrochloride reacts, and in other cases a large excess of alkali is used. When two ortho-substituents are present an oxime cannot be isolated.

Experiment 221.—Acetophenone oxime.*

$$\begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>C{:}O + H_2N{\cdot}OH, HCl + KOH \rightarrow \begin{matrix} C_6H_5 \\ CH_3 \end{matrix}\!\!>C{:}N{\cdot}OH + KCl + 2H_2O.$$

8 g. of acetophenone (1 mol) are added to a solution of 5 g. of hydroxylamine hydrochloride (1 mol) in 10 ml. of water. 3 g. of potassium hydroxide (less than 1 mol) dissolved in 5 ml. of water are added, and the mixture warmed, hot alcohol being added gradually until the solution becomes clear when shaken. The mixture is heated in a reflux apparatus on a boiling water bath for two to three hours, and then poured into 100 ml. of water. The oxime separates, and is extracted with ether, the ethereal solution dried, and the ether removed. The residue crystallizes from a little petroleum ether in colourless needles, m.p. 59°. Yield, 8 g.

Aldoximes, and the ketoximes derived from unsymmetrical ketones, may exist in two stereoisomeric forms (S.B. Chap. L, C I) represented by the formulæ, e.g.

$$\begin{matrix} CH_3O{\cdot}C_6H_4{\cdot}C{\cdot}C_6H_5 \\ \ddot{N}{\cdot}OH \end{matrix} \quad \text{and} \quad \begin{matrix} C_6H_5{\cdot}C{\cdot}C_6H_4{\cdot}OCH_3 \\ \ddot{N}{\cdot}OH \end{matrix}$$

Syn-phenyl-anisyl-ketoxime — Syn-anisyl-phenyl-ketoxime or antiphenylanisyl-ketoxime

Experiment 222.—Benzophenone-oxime, $(C_6H_5)_2C{:}N{\cdot}OH$.

Cold solutions of 1·5 g. hydroxylamine hydrochloride in water (5 ml.) and 3·5 g. potassium hydroxide in water (6 ml.) are added to a solution of 2 g. benzophenone in alcohol (15 ml.). The mixture is heated on a water bath for 2 hours and is then poured into 50 ml. of water, filtered to remove any unaltered ketone, and the filtrate acidified with dilute sulphuric acid. The precipitated oxime is crystallized from alcohol. One oxime only is obtained which consists of colourless crystals, m.p. 140°.

* *Janny*, B. 1882, **15**, 2781.

Experiment 223.—Preparation of phenyl-anisyl-ketoximes,*

$$\begin{matrix} C_6H_5 \diagdown \\ \qquad C{:}N{\cdot}OH. \\ MeO{\cdot}C_6H_4 \diagup \end{matrix}$$

5 g. of *p*-methoxy-benzophenone (Exp. 215) are dissolved in 15 ml. of 90 per cent alcohol, and a cold solution of 5 g. hydroxylamine hydrochloride (3 mols) in 10 ml. of water added. The mixture is well stirred and more water added gradually until the solution is just homogeneous. It is allowed to stand in the cold until crystals separate (60 hours). These are filtered off and recrystallized from a little alcohol; m.p. 140°.

The filtrate from the above is acidified with dilute hydrochloric acid, and on further standing deposits a fine crystalline product which after crystallization from a little alcohol yields white crystals, m.p. 116°.

Both substances are decomposed by warming with strong hydrochloric acid, regenerating the ketone.

For *Beckmann transformation* of these isomeric oximes, see Exp. 343.

C. Condensation with Hydrazines; Preparation of Hydrazones and Osazones

I. Phenylhydrazones.

Most ketones and aldehydes react with hydrazine and its derivatives, yielding hydrazones. Phenylhydrazine is the common reagent (see preparation, Exp. 199); but *p*-nitrophenyl-, *p*-bromophenyl-, 2:4-dinitrophenyl-, *as*-diphenyl-, and methyl-phenyl-hydrazines are also used. The reaction is of the type,

$$C_6H_5CH{:}O + H_2N{\cdot}NH{\cdot}C_6H_5 \rightarrow C_6H_5{\cdot}CH{:}N{\cdot}NH{\cdot}C_6H_5 + H_2O.$$

Experiment 224.—Benzylidine-phenylhydrazone from benzaldehyde.†

1 ml. of phenylhydrazine is shaken with the same volume of 50 per cent acetic acid, 5 ml. of water are added, and the mixture shaken until a clear solution is obtained. 0·5 ml. of benzaldehyde is added, and the mixture is gently warmed and vigorously shaken. After standing for a short time, the yellow flocculent precipitate which settles out is filtered, washed

* *Schäfer*, A. 1891, **264**, 158. † *E. Fischer*, A. 1878, **190**, 134.

with a small amount of dilute acetic acid, and dried on a porous plate. It crystallizes from dilute alcohol in prisms, m.p. 157°.

Experiment 225.—Anisaldehyde-2:4-dinitrophenylhydrazone.* 1 g. of the dinitrophenylhydrazine (Exp. 180) is dissolved in 2 ml. concentrated sulphuric acid, 15 ml. of alcohol are added, and to this *freshly* prepared solution is added an alcoholic solution of 0·5 g. anisaldehyde. The hydrazone separates after a short time and, after washing with water and drying, can be crystallized from xylene. It forms bright red leaflets, m.p. 250°.

For the preparation of the 2:4-dinitrophenylhydrazones from an unknown aldehyde or ketone the following procedure is recommended.

A stock solution of the reagent is prepared as follows:

1 g. 2:4-dinitrophenylhydrazine is dissolved in 2 ml. concentrated sulphuric acid and 15 ml. methyl alcohol gradually added.

The carbonyl compound (0·2 g.) is dissolved in methyl alcohol (2 ml.) and the solution added to an equal volume of the reagent. If the hydrazone does not crystallize out quickly, the solution is diluted by the addition of dilute sulphuric acid. The product is filtered off and washed with cold methyl alcohol.

For melting-points, see Tables XI and XII.

II. **Phenylosazones.**

1:2-diketones, e.g. $CH_3 \cdot CO \cdot CO \cdot CH_3$, and 1:2-keto-aldehydes, e.g. $CH_3 \cdot CH_2 \cdot CO \cdot CHO$, can react with excess of phenylhydrazine, so that two $:N \cdot NH \cdot C_6H_4$ residues are introduced, and compounds containing the grouping

$$\begin{array}{l} -C{:}N \cdot NH \cdot C_6H_5 \\ -\dot{C}{:}N \cdot NH \cdot C_6H_5 \end{array}$$

are obtained. Such compounds are termed phenylosazones, and, like the hydrazones, crystallize well and have definite melting-points.

Hydroxy-aldehydes and hydroxy-ketones, which contain the hydroxyl group in the α-position with respect to the carbonyl group, also yield osazones in addition to hydrazones. Many of the simpler sugars, e.g. *d*-glucose and *d*-fructose, &c., yield osazones of this type. The osazone is produced as the result of three distinct reactions (S.B. Chap. XIV, A):

* *Brady*, J. C. S. 1931, 757.

1. The formation of the phenylhydrazone.

2. The oxidation of the α->CHOH group to a :C:O group at the expense of the excess of phenylhydrazine.

3. The introduction of a second hydrazino-group by condensation of this carbonyl group with a third molecule of the hydrazine.

The osazones derived from the sugars are used largely for their identification.

Experiment 226. — Phenylglucosazone, $CH_2OH\cdot(CHOH)_3\cdot C(:N\cdot NH\cdot C_6H_5)\cdot CH:N\cdot NH\cdot C_6H_5$, **from** ***d*-glucose,*** $CH_2OH\cdot(CHOH)_3\cdot CHOH\cdot CHO$.

2 g. of phenylhydrazine are treated with 2 ml. of 50 per cent acetic acid and 10 ml. of water, and the mixture shaken until a clear solution is obtained.† A solution of 1 g. of glucose in 5 ml. of water is then added, and the mixture warmed on a water bath for an hour. Yellow crystals of the phenylosazone settle out; these are filtered off and washed with a little dilute acetic acid. The substance is further purified by dissolving in a little hot pyridine with addition of hot alcohol and a little water, from which it is deposited as yellow crystals; m.p. 205°.

The same osazone is obtained from fructose and *d*-mannose. Osazones of other sugars are prepared in a similar manner.

D. Condensation with Semicarbazide; Formation of Semicarbazones ‡

Semicarbazide, $NH_2\cdot CO\cdot NH\cdot NH_2$, condenses readily with compounds containing the carbonyl grouping with the formation of semicarbazones:

$$\begin{matrix} R \\ R \end{matrix}\!\!>\!C\boxed{:O + H_2}N\cdot NH\cdot CO\cdot NH_2 \rightarrow \begin{matrix} R \\ R \end{matrix}\!\!>\!C:N\cdot NH\cdot CO\cdot NH_2 + H_2O.$$

The reagent is generally used in the form of its hydrochloride. This is dissolved in water and mixed with an excess of concentrated sodium acetate solution. The aldehyde or ketone is then added, with sufficient alcohol to render the solution clear.

* *E. Fischer*, B. 1884, **17**, 579; 1887, **20**, 821.

† A solution of the hydrochloride (2 g.) of the base and sodium acetate (3 g.) in water (15 ml.) may be substituted for the above solution.

‡ *Thiele* and *Stange*, A. 1894, **283**, 1.

Experiment 227.—Acetone-semicarbazone, $(CH_3)_2\cdot C{:}N\cdot NH\cdot CO\cdot NH_2$.

0·5 g. of semicarbazide hydrochloride is dissolved in 2 ml. of a strong solution of sodium acetate and 1 ml. of acetone added. The mixture is shaken well and allowed to stand for several hours. The condensation product crystallizes in the form of needles, and is recrystallized from a small quantity of alcohol; m.p. 187° (with decomposition).

Experiment 228.—Benzaldehyde-semicarbazone,* $C_6H_5\cdot CH{:}N\cdot NH\cdot CO\cdot NH_2$.

A few drops of benzaldehyde are shaken with a solution of 0·5 g. of semicarbazide hydrochloride in water. A complete separation of the condensation product occurs. M.p. 214° (decomp.).

Experiment 229.—Aceto-acetic ester semicarbazone.

$$\left.\begin{matrix} CH_3 \\ COOC_2H_5\cdot CH_2 \end{matrix}\right> C{:}\boxed{O + H_2}N\cdot NH\cdot CO\cdot NH_2$$

$$\rightarrow \left.\begin{matrix} CH_3 \\ COOC_2H_5\cdot CH_2 \end{matrix}\right> C{:}N\cdot NH\cdot CO\cdot NH_2 + H_2O.$$

1 g. of semicarbazide hydrochloride and 1·5 g. of sodium acetate crystals are dissolved in the smallest possible quantity of water. 1 g. of aceto-acetic ester (cf. Exp. 236) is added, and sufficient alcohol to dissolve the ester completely. The mixture is warmed gently, then shaken vigorously and allowed to stand for some time. The semicarbazone separates in the form of white crystalline needles, which are filtered off and recrystallized from ether. M.p. 129°.

Diorthosubstituted ketones in many cases do not yield oximes, phenyl-hydrazones,† &c. (S.B. Chap. XXXVI.)

The oximino, :N·OH, phenylhydrazino, :N·NHPh, and semicarbazino, $:N\cdot NH\cdot CO\cdot NH_2$, groups can be removed from these condensation products, and the aldehyde or ketone regenerated by means of the following reactions:

(*a*) Boiling with 30 per cent sulphuric acid; (*b*) osazones and hydrazones derived from sugars are decomposed when a boiling aqueous solution of the compound is shaken with benzaldehyde.‡

* *Thiele*, B. 1894, **27**, 32.

† *Baum*, B. 1895, **28**, 3209; *V. Meyer*, B. 1896, **29**, 830 836.

‡ *Fischer* and *Armstrong*, B. 1902, **35**, 3141; *Herzfeld*, B. 1895, **28**, 442.

XXIII. QUINONES
(S.B. Chap. XXV, E)

Quinones are compounds derived from aromatic hydrocarbons and their derivatives by the replacement of two atoms of hydrogen by two of oxygen, e.g. $C_6H_4O_2$. These are divided into para-quinones and ortho-quinones, the oxygen atoms being in the para- and ortho- positions in the respective groups.

Modes of Formation.

Method I.—Para-quinones are readily obtained by the oxidation of many aniline and phenol derivatives belonging to the para-series, or of the amino-compounds themselves, e.g.

$$C_6H_5NH_2 \rightarrow C_6H_4\begin{cases} O\ (1) \\ O\ (4) \end{cases}$$

$$(1)\ CH_3{\cdot}C_6H_4{\cdot}NH_2\ (2) \rightarrow (1)\ CH_3{\cdot}C_6H_3\begin{cases} O\ (2) \\ O\ (5). \end{cases}$$

Experiment 230.—*p*-Benzoquinone, $C_6H_4\begin{cases} O\ (1) \\ O\ (4) \end{cases}$, **from aniline.***

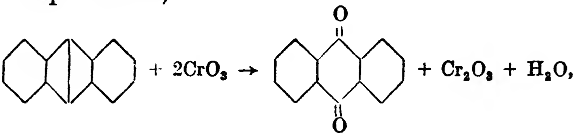
A solution of 20 g. of aniline in a mixture of water (600 ml.) and concentrated sulphuric acid (160 ml.) is placed in a stout beaker immersed in ice-cold water, and is kept automatically agitated by means of a stirrer worked by a water turbine. A solution of 20 g. of sodium dichromate in 100 ml. of water is added slowly drop by drop from a dropping funnel. The mixture is left in a cool place overnight, and then a further solution of sodium dichromate (40 ml. in 200 ml. of water) added under conditions similar to the above. After four or five hours the mass is extracted three times with ether, the ethereal solution dried with calcium chloride, and the ether removed in the usual manner. The crude quinone is purified by distillation in steam, or by sublimation, and forms orange-yellow needles with a characteristic pungent odour. M.p. 116°. Yield, 19 g., i.e. 82 per cent.

Experiment 231.—Toluquinone, $CH_3{\cdot}C_6H_3O_2$ [CH_3:O:O = 1:2:5], **from *o*-toluidine.**

Similar to previous preparation, except that *o*-toluidine is substituted for aniline. Yield, 19 g.; m.p. 67°.

* *Schniter*, B. 1887, 20, 228.

Hydrocarbons with condensed benzene nuclei (S.B. Chaps. XXXI, XXXII) are in many cases readily oxidized to the corresponding quinones, thus anthracene to anthraquinone (S.B. Chap. XXXII):



and phenanthrene to phenanthraquinone (S.B. Chap. XXXII, B):

$$\begin{matrix} C_6H_4\cdot CH \\ C_6H_4\cdot CH \end{matrix} \rightarrow \begin{matrix} C_6H_4\cdot CO \\ C_6H_4\cdot CO \end{matrix}$$

Experiment 232.—Oxidation of anthracene to anthraquinone.*

A solution of 20 g. of chromic anhydride (Chap. XXXVIII) in 10 ml. of water and 90 ml. of glacial acetic acid is added very gradually through a dropping funnel to a boiling solution of 10 g. of anthracene in 120 ml. of glacial acetic acid contained in a round-bottomed flask fitted with a reflux condenser, the mixture being meanwhile kept in vigorous ebullition. When the addition, which should take about an hour, is completed, the mixture, which is of a deep green colour, is allowed to cool, and then poured into a large excess of cold water. The crude anthraquinone is removed, washed with dilute alkali and water, dried and purified by sublimation (fig. 19). It forms yellow needles; m.p. 285°, b.p. 382°. Yield, 10 g.

1:4-Naphthaquinone can be prepared in a similar manner from naphthalene.

Method II.—Both ortho- and para-quinones may be prepared by the oxidation of the corresponding dihydroxy-compounds. Thus *o*-benzoquinone is obtained by oxidizing an ethereal solution of catechol with silver oxide.†

$$OH\cdot C\begin{matrix} \diagup C(OH)\cdot CH \diagdown \\ \diagdown CH{=}CH \diagup \end{matrix}CH \rightarrow CO\begin{matrix} \diagup CO\cdot CH \diagdown \\ \diagdown CH{:}CH \diagup \end{matrix}CH.$$

p-Quinones are readily obtained from *p*-dihydroxy-derivatives of benzene and its homologues by oxidation with ordinary oxidizing agents, e.g. quinone from quinol (Exp. 139).

* *Graebe* and *Liebermann*, A. Sup. 1870, **7**, 285.
† *Willstätter* and *Pfannenstiel*, B. 1904, **37**, 4744; 1908, **41**, 2580.

Experiment 233.—Camphorquinone from camphor.*

A mixture of camphor (5 g.). selenium dioxide (6 g.) in a fine powder, and acetic anhydride (5 ml.) is heated in a tube fitted with a condenser at 140–150° for 3–4 hours. The reaction proceeds vigorously with the deposition of selenium as an amorphous black powder. The cooled product is filtered, the selenium well washed with a little glacial acetic acid, and the orange-yellow filtrate carefully neutralized with potassium hydroxide solution. The precipitated camphorquinone is crystallized from light petroleum (60–80°) and forms golden yellow needles, m.p. 198–199°. Yield, 5·2 g.

Its monosemicarbazone melts at 228–229° and its *p*-bromophenylhydrazone at 215–216°.

Method III.—*o*-Benzoylbenzoic acid (Exp. 216) and its substituted derivatives readily undergo dehydration in the presence of concentrated sulphuric acid, yielding anthraquinone or derivatives.

$$C_6H_4\left\langle\begin{array}{l}CO\cdot OH\\ CO\cdot C_6H_5\end{array}\right. \rightarrow C_6H_4\left\langle\begin{array}{c}CO\\ CO\end{array}\right\rangle C_6H_4.$$

Experiment 234.—Anthraquinone from *o*-benzoylbenzoic acid.

2 g. of the acid are dissolved in 2 ml. conc. sulphuric acid by heating in a boiling-water bath. The solution is cooled and poured into 50 ml. of cold water. The precipitate is filtered, washed and dried. M.p. 285° (cf. Exp. 232).

General Characteristics of Quinones.

The quinones as a group are characterized by their yellow (or red) colour and by the formation of mono- and di-oximes. With the exception of the anthraquinones they are readily reduced by sulphurous acid to the corresponding phenols. (cf. Exp. 139).

The benzoquinones form additive compounds with bromine, e.g. $C_6H_4O_2\cdot Br_2$, and $C_6H_4O_2\cdot Br_4$, and also additive products with phenols.

Experiment 235.—Quinhydrone from quinol and quinone.

0·5 g. of each of the two components is dissolved in warm water and the solutions mixed; brilliant green crystals of the additive compound separate. In solution it gives the characteristic chemical properties of its components.

* *Evans, Ridgion and Simonsen,* J. C. S. 1934, 137.

XXIV. CLAISEN CONDENSATION; ETHYL ACETOACETATE: ITS REACTIONS AND CONDENSATIONS. (S.B. Chap. IX, H2.)

A. Claisen Condensation

The condensation of two molecules of an ester (e.g. ethyl acetate, Exp. 236), or of two molecules of different esters (Exp. 239), or of one molecule of an ester with one molecule of a ketone (Exp. 240), or of one or two molecules of an aldehyde with a ketone (Exp. 241), under the influence of sodium or sodium ethoxide, is termed *Claisen's* reaction, and is one of the best methods for preparing β-ketonic esters and β-di-ketones. The reaction may be represented as:

$$CH_3 \cdot CO \cdot OEt + HCH_2 \cdot CO \cdot OEt \rightarrow CH_3CO \cdot CH_2 \cdot CO \cdot OEt + EtOH,$$

and takes place, with the formation of a series of intermediate compounds, by the action of one of a number of catalysts, such as sodium ethylate, sodamide, sodium triphenylmethyl and certain Grignard reagents. The function of the catalyst in the changes has been much discussed, but recent work has brought definite proof of the ionic nature of the reactions.†

Experiment 236.—Ethyl acetoacetate, $CH_3 \cdot CO \cdot CH_2 \cdot COOC_2H_5$, **from ethyl acetate and sodium.**

For the purpose of the preparation the ethyl acetate must be carefully purified and freed from traces of acetic acid and water, and *most of* the alcohol. The latter must not be completely removed, for then the reaction proceeds very slowly.

Purification of Ethyl Acetate.

The ester purified as described in Exp. 85 reacts too vigorously with sodium, and gives a poor yield of the product. It is therefore allowed to stand for a day over freshly heated granular calcium chloride in a well-stoppered bottle, filtered into a dry distilling flask and redistilled, care being taken that all parts of the apparatus are perfectly dry.

30 g. of *clean* sodium are cut into thin strips, or pressed into wire by means of a sodium press (fig. 99), and introduced

* B. 1905, 38, 709.

† For a discussion of the mechanism of this and analagous reactions consult: *Watson*, Modern Theories of Organic Chemistry, Chap. XI; or *Hammett*, Physical Organic Chemistry, Chap. XI.

into a clean, dry, round-bottomed flask. The latter is attached to a long reflux condenser inclined obliquely, and fixed on a water bath. 300 g. of the purified ethyl acetate are introduced through the condenser tube, which is then fitted with a drying tube, and after some 15 minutes the water bath is gradually warmed, the temperature being regulated so that gentle ebullition takes place within the flask. The heating is continued for 3 hours, or until all the sodium is dissolved, when a mixture of 100 g. of glacial acetic acid with an equal

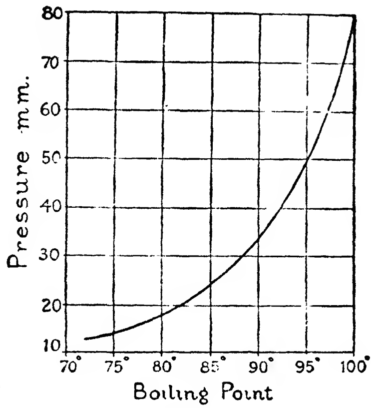


Fig. 90

quantity of water is added gradually until the contents of the flask show an acid reaction. If any solid is deposited, it is redissolved by vigorously shaking the flask. The liquid is then poured into a separating funnel containing an equal volume of saturated common salt solution, the mixture shaken, and the lower aqueous layer removed. The upper layer, consisting of ethyl acetate and ethyl acetoacetate, is fractionally distilled. For this purpose the whole is placed in a large distilling flask, one or two pieces of porous pot are added, and the flask heated in a rapidly boiling water bath until the thermometer indicates a temperature of 90–95°, when the residue in the flask is subjected to distillation under diminished pressure (fig. 9). Small amounts of impurities first pass over, and when the temperature rises to the value indicated by the curve for the given pressure (fig. 90), the receiver is changed,

and the acetoacetic ester collected. Should a large amount of liquid distil over before the correct temperature for the given pressure is attained, the first fraction is redistilled and a further yield of the ester thereby obtained. Yield, 45–50 g.

N.B.—The yield is considerably lowered if the whole experiment is not completed in one day.

The ester is a colourless mobile liquid with a pleasant fruity odour. B.p. (at 760 mm.), 181°, but it undergoes slight decomposition under these conditions; it is very sparingly soluble in water, but dissolves in alcohol and ether.

Chemical Reactions of Ethyl Acetoacetate.

Hydrolysis.—Under varying conditions the ester yields different products of hydrolysis. With dilute alkalis in the cold, the process is normal,

$$CH_3{\cdot}CO{\cdot}CH_2{\cdot}COOEt + KOH \rightarrow CH_3{\cdot}CO{\cdot}CH_2{\cdot}COOK + EtOH,$$

but it is impossible to isolate the pure acid, as it decomposes rapidly into acetone and carbon dioxide.

Ketonic Hydrolysis.—When warmed with dilute acids or alkalis (baryta water is generally used), the ester decomposes, yielding acetone and ethyl alcohol:

$$\begin{array}{l} CH_3{\cdot}CO{\cdot}CH_2\vdots{\cdot}COO\vdots C_2H_5 = CH_3{\cdot}CO{\cdot}CH_3 + CO_2 + C_2H_5OH. \\ \qquad\qquad\quad H\vdots \qquad\quad \vdots OH \end{array}$$

Experiment 237.—Heat 5 g. of ethyl acetoacetate in a reflux apparatus with 100 ml. of baryta water (saturated solution) for an hour. Distil the product, and test the distillate for acetone (Exp. 212) and ethyl alcohol (p. 120).

See also Exps. 244 and 246.

Acid Hydrolysis.—With concentrated alkalis (concentrated alcoholic potash is generally used) the ester decomposes, yielding an acetate and alcohol:

$$\begin{array}{l} CH_3{\cdot}CO\vdots{\cdot}CH_2{\cdot}COO\vdots C_2H_5 = 2CH_3COOK + C_2H_5OH. \\ \qquad\quad KO\vdots H \qquad\quad K\vdots OH \end{array}$$

Experiment 238.—Warm 5 g. of the ester with 20 ml. of concentrated alcoholic potash for a few minutes. Distil off the alcohol, neutralize the contents of the flask with hydrochloric acid, and test for an acetate (Table X, p. 413).

Acetoacetic ester gives the reactions characteristic of carbonyl compounds (Chap. XXII). For the preparation of its semicarbazone and phenylhydrazone, see Exps. 229 and 249.

The aqueous solution of the ester gives a reddish-violet coloration with ferric chloride, usually attributed to the presence of the hydroxy-group.

Other examples of the Claisen condensation.

Experiment 239.—Oxal-acetic ester,* $CO_2Et{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et$.

$$CH_3{\cdot}CO_2Et + CO_2Et{\cdot}CO_2Et + EtONa \rightarrow 2EtOH + CO_2Et{\cdot}C(ONa){:}CH{\cdot}CO_2Et$$

$$CO_2Et{\cdot}C(ONa){:}CH{\cdot}CO_2Et \rightarrow CO_2Et{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et.$$

2·3 g. of sodium wire are placed in a flask and covered with 60 ml. of anhydrous ether. 14·6 g. of pure ethyl oxalate (1 mol) are added, and then 8·8 g. of pure ethyl acetate (1 mol) are gradually introduced. The mixture is warmed gently on a water bath in a reflux apparatus until the sodium completely dissolves, care being taken to prevent overheating. On standing for several hours the product solidifies to a yellow crystalline mass, which is washed several times with dry ether. The solid product is the sodio-derivative of oxal-acetic ester; this is decomposed with dilute sulphuric acid, the flask being kept well cooled during the process. The oily ester which separates is extracted with ether, the ethereal extract washed with dilute sodium hydroxide solution, and filtered through a dry filter paper in order to remove water as much as possible. It is then fractionated under diminished pressure, the pure ester distilling over at 131–132°, under 24 mm. pressure. Yield, 70–80 per cent of theory.

It is a colourless liquid which decomposes during distillation under ordinary pressure. $D_{4^\circ}^{23 \cdot 5^\circ}$, 1·159.

The ester undergoes the *acid* hydrolysis into oxalic and acetic acids when warmed with concentrated alcoholic potash, and reacts with phenylhydrazine, yielding a hydrazone.

The alcoholic solution of the ester gives an intense dark-red coloration with ferric chloride.

Experiment 240.—Benzoylacetone, $C_6H_5{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}CH_3$, **from ethyl acetate and acetophenone.†**

$$CH_3{\cdot}COOEt + NaOEt + H_2CH{\cdot}CO{\cdot}C_6H_5 \rightarrow CH_3C(ONa){:}CH{\cdot}CO{\cdot}C_6H_5 + 2EtOH.$$

Sodium ethoxide free from alcohol (1 mol, cf. Chap. XXXVIII) is treated with pure ethyl acetate (2 mols), and the

* *Wislicenus*, A. 1888, **246**, 317.

† *Baeyer* and *Claisen*, B. 1887, **20**, 2180.

mixture cooled with ice. Acetophenone (1 mol) is added gradually, and the mixture solidifies to a finely crystalline yellow mass of the sodio-derivative of benzoylacetone. This is washed with ether, then dissolved in water and decomposed with acetic acid, when benzoylacetone crystallizes as fine white prisms. M.p. 60–61°; b.p. 260–261°. Yield, 80–90 per cent of theory.

In addition to the sodio-derivative, the compound yields a copper derivative which can be prepared readily by adding a solution of cupric acetate to an alcoholic solution of benzoyl acetone. The precipitate is insoluble in water, but crystallizes from benzene in the form of deep-green needles.

Experiment 241.—Dibenzalacetone, $C_6H_5{\cdot}CH{:}CH{\cdot}CO{\cdot}CH{:}CH{\cdot}C_6H_5$, **from benzaldehyde and acetone.**

10 g. of benzaldehyde and 2·75 g. of pure acetone are mixed with 100 ml. of alcohol in a flask. A solution of 2 g. of sodium hydroxide in 100 ml. of water is added and the mixture shaken. After standing for an hour with occasional shaking, the product has separated as pale-yellow crystals which are removed, well washed with water, and recrystallized from hot alcohol. M.p. 112°. Yield, 8–10 g.

B. Alkyl Derivatives of Ethyl Acetoacetate

The most important property of ethyl acetoacetate and other β-ketonic esters is their ability to react with sodium, one molecule of the ester taking up an atom of the metal with displacement of hydrogen. The sodio-compound ($CH_3{\cdot}CO{\cdot}CHNa{\cdot}COOEt$, or probably $CH_3{\cdot}C(ONa){:}CH{\cdot}CO_2Et$) reacts with various halogen compounds forming sodium halide and an alkyl derivative of the ester, e.g.

$$CH_3{\cdot}C(ONa){:}CH{\cdot}CO_2Et + C_2H_5I \rightarrow CH_3{\cdot}CI(ONa){\cdot}CH(C_2H_5){\cdot}CO_2Et$$
$$\rightarrow NaI + CH_3{\cdot}CO{\cdot}CH(C_2H_5){\cdot}CO_2Et.$$

The product of this reaction can also react with metallic sodium forming a sodio-derivative, which can be decomposed in a similar manner by halogen compounds.

Experiment 242.—Ethylacetoacetic ester from acetoacetic ester * (see equation above).

5·7 g. of clean sodium (1 atom) are dissolved in 70 g. of

* *Conrad* and *Limpach*, A. 1878, **192**, 155.

absolute alcohol in a reflux apparatus, and the solution treated with 32·5 g. (1 mol) of acetoacetic ester. 40 g. of ethyl iodide are added, and the mixture heated on a water bath until it shows a neutral reaction (about 2 hours). The alcohol is distilled off, the residual oil shaken with water and then extracted with ether. The ethereal solution is dried with anhydrous potassium carbonate, the ether removed, and the residue fractionally distilled. The portion which boils at 190–198° is collected separately. Yield, 80 per cent of theory. The ester is a colourless oil, b.p. 198°. $D_{4°}^{16°}$, 0·9834.

It reacts with metallic sodium, and gives a blue coloration with ferric chloride.

Experiment 243.—Methylethylacetoacetic ester from ethylacetoacetic ester.

$$CH_3\cdot CO\cdot CHEt\cdot CO_2Et \rightarrow CH_3\cdot C(ONa){:}CEt\cdot CO_2Et + CH_3I \longrightarrow CH_3\cdot CO\cdot CEtMe\cdot CO_2Et.$$

The method of Conrad and Limpach (Exp. 242) is applied, theoretical amounts of the reacting substances being taken. Yield, 75–80 per cent of theory. The product is a colourless oil, b.p. 200–201°. $D^{22°}$, 0·947. It does not react with metallic sodium, but gives a violet coloration with ferric chloride.

These alkyl derivatives of acetoacetic ester can undergo ketonic or acid hydrolysis in the same manner as ethyl-acetoacetate itself.

Experiment 244.—Methyl β-butyl ketone from methylethylacetoacetic ester.*

$$\begin{matrix}CH_3\cdot CO\cdot CMeEt\cdot CO_2\,Et \\ \quad\quad\quad\quad\quad\quad\quad H \quad\;\; OH\end{matrix} \rightarrow CH_3\cdot CO\cdot CHMeEt + CO_2 + EtOH.$$

20 g. of methylethylacetoacetic ester are boiled in a reflux apparatus with 100 ml. of 10 per cent aqueous potassium hydroxide solution for 5 hours. At the end of this time the reaction is completed and the product is distilled. A colourless oil passes over together with water, and is extracted with ether. The ethereal solution is dried with calcium chloride, the ether removed and the residue distilled, when the ketone passes over as a light colourless oil, with an odour of peppermint. B.p. 118°; $D_{4°}^{14·5°}$, 0·8181.

* *Wislicenus*, A. 1883, **219**, 308.

C. Condensations of Ethyl Acetoacetate

Experiment 245.—Ethyl diacetosuccinate by the action of iodine on ethyl sodio-acetoacetate.*

$$\begin{matrix} CH_3\cdot CO\cdot CHNa\cdot COOEt \\ CH_3\cdot CO\cdot CHNa\cdot COOEt \end{matrix} + I_2 = \begin{matrix} CH_3\cdot CO\cdot CH\cdot COOEt \\ CH_3\cdot CO\cdot \dot{C}H\cdot COOEt \end{matrix} + 2NaI.$$

450 ml. of *anhydrous* ether (Exp. 29) are placed in a 1500 ml. flask and 13·8 g. of clean sodium in the form of wire added. The flask is fitted to a reflux condenser, and 78 g. of ethyl acetoacetate are added gradually. The vessel is shaken occasionally to assist the solution of the sodium, and when this is complete, 76·5 g. of iodine dissolved in 300 ml. of anhydrous ether are added gradually, the addition being continued only so long as the colour disappears after each addition; sodium iodide separates out and is removed by filtration. The ether is removed from the filtrate, and the residue of ethyl diacetosuccinate recrystallized from glacial acetic acid. It forms colourless thin plates, m.p. 88°. Yield, 30 g., i.e. 40 per cent of theory.

Like ethyl acetoacetate and other ketonic esters, the compound exists in tautomeric forms. A number of these have been isolated in pure form.†

This substance is a γ-diketone, and as such readily undergoes transformation into closed-chain derivatives. When shaken with dilute alkalis, it undergoes ketonic hydrolysis with the formation of the simple γ-diketone, acetonyl-acetone:

$$\begin{matrix} H \vdots \vdots OH \\ CH_3\cdot CO\cdot CH \vdots \cdot COO \vdots Et \\ CH_3\cdot CO\cdot \dot{C}H \vdots \cdot COO \vdots Et \\ H \vdots \vdots OH \end{matrix} = \begin{matrix} CH_3\cdot CO\cdot CH_2 \\ CH_3\cdot CO\cdot \dot{C}H_2 \end{matrix} + 2CO_2 + 2EtOH.$$

Experiment 246.—Acetonyl-acetone from ethyl diacetosuccinate.‡

A solution of ethyl diacetosuccinate (Exp. 245) is obtained by vigorously shaking 15 g. of the ester with rather more than the theoretical amount of a 5 per cent aqueous solution of sodium hydroxide (1 mol of ester requires 4 mols of alkali). The solution is allowed to stand at the room temperature for

* *Knorr* and *Haber*, B. 1894, **27**, 1155.
† *Knorr*, A. 1896, **293**, 101; 1899, **306**, 332.
‡ *Knorr*, B. 1889, **22**, 169.

several days until diacetosuccinic ester no longer separates when a test portion is acidified with hydrochloric acid. The alkaline solution is then saturated with potassium carbonate; the acetonyl-acetone separates as an oil, which is extracted with ether. The ethereal solution is shaken with saturated salt solution, separated, dried, and distilled. Yield, 5–6 g., i.e. 80–85 per cent of theory.

The diketone is a liquid with an agreeable odour; b.p. 194°; $D^{15°}$, 0·995. It is miscible with water, alcohol, and ether.

The γ (1·4) diketones readily condense with the formation of closed-ring compounds. Thus, acetonyl-acetone when heated in a sealed tube with dehydrating agents (e.g. zinc chloride) yields dimethylfurane:

$$\begin{array}{l} CH_2{\cdot}CO{\cdot}CH_3 \\ | \\ CH_2{\cdot}CO{\cdot}CH_3 \end{array} \rightarrow \left.\begin{array}{l} CH{:}C(CH_3) \\ | \\ CH{:}C(CH_3) \end{array}\right\rangle O.$$

With alcoholic ammonia under similar conditions it forms dimethylpyrrole:

$$\begin{array}{l} CH_2{\cdot}CO{\cdot}CH_3 \\ | \\ CH_2{\cdot}CO{\cdot}CH_3 \end{array} + NH_3 = \left.\begin{array}{l} CH{:}(CH_3) \\ | \\ CH{:}(CH_3) \end{array}\right\rangle NH;$$

and with phosphorus pentasulphide a thiophene derivative is formed.

$$\begin{array}{l} CH_2{\cdot}CO{\cdot}CH_3 \\ | \\ CH_2{\cdot}CO{\cdot}CH_3 \end{array} + P_2S_5 \rightarrow \underset{\text{Thioxene}}{\left.\begin{array}{l} CH{:}C(CH_3) \\ | \\ CH{:}C(CH_3) \end{array}\right\rangle S.}$$

Experiment 247.—Thioxene (1:4-dimethyl-thiophene) from acetonyl-acetone.*

Three parts of acetonyl-acetone (Exp. 246) are heated with two parts of finely powdered phosphorus pentasulphide in a sealed tube at 140–150° for an hour. On cooling, a colourless liquid and a solid are obtained; the former is poured off and fractionally distilled. The distillation is repeated over metallic sodium, when the thioxene is obtained as a colourless mobile liquid; b.p. 134–135°. Yield, 50–60 per cent of theory.

Colour reaction for thiophene derivatives.—Thiophene compounds give intense colorations with solutions of isatin in concentrated sulphuric acid, e.g. thioxene gives a cherry-red colour, which changes to reddish-brown on warming.

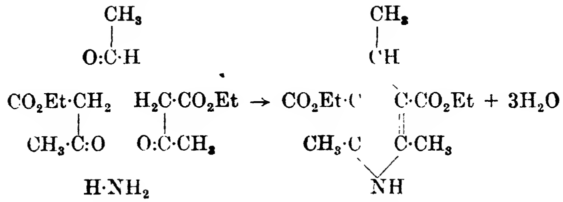
* *Paal*, B. 1885, 18, 2251.

Experiment 248.—Hantzsch's synthesis of pyridine derivatives: Condensation of ethyl acetoacetate with aldehyde-ammonia.

(*a*) **Ethyl dihydro-collidine-dicarboxylate.***

$$2CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et + CH_3{\cdot}CHO, NH_3 = C_5H_2N(CH_3)_3(CO_2Et)_2 + 3H_2O;$$

or represented structurally:



(*To be conducted in a fume chamber.*)

26 g. of ethyl acetoacetate are mixed with 6·75 g. of aldehyde-ammonia (Exp. 200) in a beaker, and warmed gently for about three minutes at 100–110° (stir with a thermometer). To the product is added an equal volume of dilute hydrochloric acid, and the mixture is stirred until it sets into a hard solid mass. The mass is powdered, filtered, and washed with dilute hydrochloric acid and water. A small portion is recrystallized from hot alcohol, and then forms colourless plates with a bluish fluorescence, m.p. 131°. It is insoluble in water, sparingly soluble in alcohol, ether, and carbon disulphide, but is readily soluble in benzene.

(*b*) **Oxidation of ethyl dihydro-collidine-dicarboxylate to ethyl collidine-dicarboxylate.** (*To be conducted in a fume chamber.*)

$$C_5H_2N(CH_3)_3(CO_2Et)_2 + O \rightarrow C_5N(CH_3)_3(CO_2Et)_2 + H_2O.$$

Nitrous acid is generally used as the oxidizing agent. This is prepared by the action of concentrated nitric acid on *small lumps* of arsenious oxide. On warming gradually a steady stream of nitrous fumes is generated; these are passed through an empty wash bottle and thence into the solution.

The crude dihydro-ester from (*a*) is treated with an equal weight of alcohol in a small flask; complete solution does not

* *Hantzsch*, A. 1882, **215**, 1.

take place. Nitrous fumes are led into the flask until a test portion treated with hydrochloric acid becomes clear. Heat is developed during the oxidation and all the ester goes into solution; if necessary, the flask is cooled by immersing in water. The alcohol is evaporated off on a water bath and the residue neutralized by the addition of sodium carbonate solution. The oil which separates is extracted with ether, the extract dried by the addition of a small stick of caustic potash, the ether removed and the residue distilled. The fraction passing over between 290° and 310° is collected separately and redistilled. The pure ester is a yellow oil, b.p. 308–310°.

(*c*) **Hydrolysis of ethyl collidine-dicarboxylate: Potassium collidine-dicarboxylate.**

$$C_5N(CH_3)_3(CO_2Et)_2 + 2KOH = C_5N(CH_3)_3(CO_2K)_2 + 2EtOH.$$

The ester is treated with about 10 times its volume of alcoholic potash (2–3 times normal strength), and warmed in a reflux apparatus on a water bath for about four hours. The potassium salt is deposited as white crystalline crusts, and is separated from the alcoholic solution by decantation. It is washed with alcohol, then with ether, and dried. A further yield of the salt is obtained by adding ether to the alcoholic solution.

(*d*) **Removal of carboxylic groups from a closed-ring compound by distillation with lime: Preparation of collidine from potassium collidine-dicarboxylate.**

$$C_5N(CH_3)_3(CO_2K)_2 + 2Ca(OH)_2$$
$$= 2CaCO_3 + 2KOH + C_5NH_2(CH_3)_3.$$

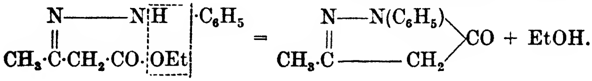
The potassium salt is powdered and mixed with about twice its weight of slaked lime. The mixture is placed in a piece of combustion tubing about 50 cm. long, sealed at one end, the other end being fitted with an adapter leading into a small receiver. The tube is heated in a combustion furnace, the rear end of which is slightly elevated. The flames at the closed end are first ignited and the others gradually, and finally the whole tube is heated as strongly as possible. The distillate is shaken with ether, the solution dried with solid potassium hydroxide, the ether removed (a very small flask is used, fig. 2), and the residue distilled.

It is a greenish-yellow liquid with an obnoxious odour, b.p. 172°, and possesses the chemical properties of a tertiary base (see Chap. XVIII, E).

Experiment 249.—1-Phenyl-3-methyl-pyrazolone by condensation of ethyl acetoacetate with phenylhydrazine.*

$$CH_3\cdot CO\cdot CH_2\cdot CO_2Et + H_2N\cdot NH\cdot C_6H_5 = CH_3\overset{N-NH\cdot C_6H_5}{\overset{\|}{C}}\cdot CH_2\cdot CO_2Et + H_2O$$

Ethyl acetoacetate phenylhydrazone



5 g. of phenylhydrazine are added to 6·25 g. of ethyl acetoacetate in a small flask and well shaken. The water formed is removed from the oily condensation product, which is then heated on a water bath until a test portion on cooling or treating with ether becomes quite solid (about 2 hours). The warm liquid is poured into a little ether; the white crystalline mass which separates is washed with ether and dried at 100°. Yield almost quantitative. It crystallizes from hot water as white crystals, m.p. 127°; is almost insoluble in cold water, ether, and light petroleum, fairly soluble in hot water, and easily soluble in alcohol.

It possesses both basic and acidic properties, and thus dissolves in both acids and alkalis.

D. Determination of Enol in Keto-Enolic Mixtures

Most β-ketonic esters and β-diketones and certain ketones containing the group $\cdot CH_2\cdot CO\cdot$ exist in solution or in the liquid form as mixtures of two tautomeric forms—the keto and the enol—and the percentage of enol in such a mixture can be readily determined by K. H. Meyer's method.†

This is based on the general principle that in the presence of bromine the enol forms a dibromide which decomposes into HBr and a bromo-ketone. The amount of this ketone is estimated by removing any excess of bromine by the addition of β-naphthol, adding potassium iodide, when the HI formed reduces the bromo-ketone and liberates the equivalent quantity of free iodine, which can be estimated by standard thiosulphate solution.

$$\cdot C(OH){:}CH\cdot \rightarrow \cdot CBr(OH)\cdot CHBr\cdot \rightarrow \cdot CO\cdot CHBr\cdot$$
$$\cdot CO\cdot CHBr\cdot + 2HI \rightarrow \cdot CO\cdot CH_2\cdot + HBr + I_2.$$

* *Knorr*, B. 1883, **16**, 2597. † B. 1911, 2718, 2843.

Experiment 250.—Determination of percentage of enol in ethyl acetoacetate.

1 g. of the ester is dissolved in alcohol and made up to 200 ml. To 20 ml. of this solution is added an approximately 5 per cent solution of bromine in alcohol until the mixture is distinctly coloured. The excess of bromine is removed by the addition of a 5 per cent alcoholic solution of β-naphthol, which is quickly added until the bromine colour disappears, after which 10 ml. of a 5 per cent solution of acidified potassium iodide is run in and the liberated iodine titrated with a standard solution of sodium thiosulphate.

1 ml. 0·1 N. thiosulphate ≡ 0·065 g. enol.

XXV. ETHYL MALONATE AND ITS USE AS A SYNTHETICAL REAGENT
(S.B. Chap. X.)

Experiment 251.—Ethyl malonate, $CH_2(CO_2Et)_2$, from chloroacetic acid.* (*To be conducted in a fume chamber.*)

$$CH_2Cl{\cdot}CO_2Na + KCN = CN{\cdot}CH_2{\cdot}CO_2Na + KCl$$
$$2CN{\cdot}CH_2{\cdot}CO_2Na + 4EtOH + 2H_2SO_4 = 2CH_2(CO_2Et)_2 + Na_2SO_4 + (NH_4)_2SO_4.$$

A solution of 50 g. of chloracetic acid in 100 ml. of water is warmed to 50° in a large flask, and neutralized with 45 g. of sodium bicarbonate added in small portions until an alkaline reaction is obtained. The temperature is kept at 55–60° until all the carbon dioxide is evolved. Then 40 g. of potassium cyanide (98 per cent) in small pieces is added with stirring, but without further warming, until the vigorous reaction which occurs has moderated. After heating on a water bath for half an hour the flask is connected with a condenser and receiver (cf. figs. 5 and 9) and the latter with a suction pump, and heated on the water bath under diminished pressure until the whole of the water has been removed and the mass is

* *Claisen* and *Venable*, A. 1883, **218**, 131; *Noyes*, J. A. C. S. 1896, **18**, 1105–6; *Scarborough*, P. 1914, **30**, 306.

quite dry.* The flask is then attached to a reflux apparatus, and the almost colourless contents gradually treated with a cooled mixture of 100 ml. of absolute alcohol and 80 ml. of concentrated sulphuric acid, and heated on the water bath for four hours with occasional shaking. 100 ml. of water are then added, the mixture shaken well and filtered, and the undissolved salt washed several times on the filter with ether. More ether is added to the mixed filtrate and washings, and the whole well shaken. The ethereal extract is carefully treated with dilute sodium carbonate solution (carbon dioxide is evolved, therefore shake carefully) until an alkaline reaction is given. It is then dried over fused sodium sulphate, the ether removed, and the residue distilled. Yield, 50 g., i.e. 60 per cent of theory.

Ethyl malonate is a colourless liquid, b.p. 198°; $D_{4^\circ}^{18^\circ}$ 1·068.

Ethyl malonate yields sodio-derivatives in much the same manner as does ethyl acetoacetate (cf. Chap. XXIV, A), and the sodium atoms in these compounds can be replaced by alkyl groups, &c. The mono- and di-alkylated malonic and acetic acids can be synthesized by this process.

Experiment 252.—Introduction of an alkyl group into malonic ester. Ethylmalonic ester.†

$$CH_2(CO_2Et)_2 + NaOEt = \underset{\text{Sodio-ethyl malonate}}{CHNa(CO_2Et)_2} + EtOH$$

$$CHNa(CO_2Et)_2 + EtI = \underset{\text{Ethylmalonic ester}}{CHEt(CO_2Et)_2} + NaI.$$

2·3 g. of sodium are dissolved in 25 g. of absolute alcohol in a flask fitted with a reflux condenser, and when solution is complete 16 g. of pure ethyl malonate are added. A white solid which consists of sodio-ethyl malonate separates; 20 g. of ethyl iodide are then added slowly from a dropping funnel, the flask being shaken well during the operation. The mass dissolves gradually, heat is developed, and a fine precipitate of sodium iodide is deposited. The mixture is finally heated on a water bath until it no longer shows an alkaline reaction (1–2 hours). The alcohol is distilled off on a vigorously boiling water (or brine) bath, the residue treated with water and the ester extracted with ether. After dehydration with calcium

* The solution may be evaporated down in an open dish on a sand bath with constant stirring until a thermometer immersed in the dish registers 130–135°. The method described above gives a better yield.

† *Conrad*, A. 1880, **204**, 134.

chloride, the ether is removed and the residue distilled, when the product is obtained as a colourless liquid with fruity odour. B.p. 206–208°; $D_{4°}^{18°}$, 1·008. Yield, 15 g.

Experiment 253.—Hydrolysis of ethyl ethylmalonate. Ethylmalonic acid, $CHEt(CO_2H)_2$.

10 g. of the ester are added gradually to a concentrated (56 per cent) solution of potassium hydroxide (about double the theoretical amount should be used) in a reflux apparatus. The mixture forms an emulsion which soon solidifies to a white mass of ethyl potassium ethylmalonate; the whole is carefully heated on a water bath until a clear solution is obtained (about half an hour is required), when the hydrolysis may be regarded as complete. The product is diluted with water, neutralized with strong hydrochloric acid, and precipitated as the calcium salt by means of a concentrated solution of calcium chloride. This salt is filtered, dried, and decomposed with strong hydrochloric acid, and the free ethylmalonic acid extracted by shaking *several times* with ether. The ethereal solution is dried with calcium chloride and the ether removed. The liquid residue solidifies on standing; it is recrystallized from a small quantity of water with the addition of animal charcoal if the crystals are coloured, and forms colourless rhombic prisms, m.p. 111·5°. It is soluble in water, alcohol, and ether.

Malonic acid and its derivatives undergo decomposition when heated to fairly high temperatures, yielding carbon dioxide and the corresponding mono-carboxylic acid. The process, therefore, provides a means for the synthesis of the higher acids of the acetic series.

Experiment 254.—Butyric acid from ethylmalonic acid.

$$CH(C_2H_5)(CO_2H)_2 = C_2H_5{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H + CO_2.$$

The ethylmalonic acid prepared in the last experiment is placed in a small fractionating flask, and fixed in an oil or metal bath at an oblique angle so that the side tube is inclined upwards. The flask is closed with a cork carrying a thermometer, the bulb of which is immersed in the substance. Heating is conducted at a temperature of 180° until no more carbon dioxide is evolved. The residue, consisting of butyric acid, is distilled over in the usual manner, and is obtained as a colourless liquid with a rancid odour. B.p. 162–163°.

Ethyl malonate in the form of its sodio-derivative reacts

not merely with alkyl halides but also with acyl halides and halogen derivatives of esters, e.g. ethyl chloracetate, ethyl α-bromopropionate.

$$CHNa(CO_2Et)_2 + CH_2Br{\cdot}CO_2Et \rightarrow CO_2Et{\cdot}CH_2{\cdot}CH(CO_2Et)_2$$
$$\rightarrow CO_2H{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H.$$

When an ester of an α-halogen derivative of a fatty acid is used and the product hydrolysed a substituted succinic acid is obtained, e.g. from ethyl α-bromopropionate, methyl-succinic acid, $CO_2H{\cdot}CHMe{\cdot}CH_2{\cdot}CO_2H$. The yield is not very good, as appreciable amounts of isomeric glutaric acid derivatives are formed. The formation of glutaric acid can be almost completely avoided by using ethyl cyanoacetate in place of ethyl malonate.* This is due to the fact that the ethyl acrylate, formed by the elimination of hydrogen bromide from the ethyl α-bromopropionate, condenses with the ethyl malonate yielding the ester of a tricarboxylic acid, and this when hydrolysed yields glutaric acid. When ethyl cyanoacetate is employed its sodio-derivative is practically insoluble in alcohol, the solution is practically neutral, and there is not the same tendency for the elimination of hydrogen bromide and formation of ethyl acrylate.

Experiment 255.—Methyl-succinic acid from ethyl cyanoacetate and ethyl α-bromopropionate.†

28·5 g. of ethyl cyanoacetate are added to a solution of 5·75 g. of sodium in 70 ml. of absolute alcohol. The insoluble sodio-derivative separates, and to the pasty mass 42 g. of ethyl α-bromopropionate are added gradually. The mixture is heated in a reflux apparatus for an hour on the water bath, when the solution is quite neutral. It is poured into water, extracted with ether, the ethereal solution washed with dilute sodium carbonate, then with water, and finally dried with calcium chloride. After removal of the ether, a yellow oil is obtained which is fractionated under reduced pressure; the fraction boiling at 140–165°/24 mm. is collected and redistilled, and the fraction passing over at 160–165°/17 mm. collected. This consists of ethyl β-methyl-α-cyanosuccinate, $CO_2Et{\cdot}CH(CN){\cdot}CH(CH_3){\cdot}CO_2Et$, and the yield is 70 per cent of theoretical. This ester is boiled in a reflux apparatus with 6–8 times its volume of concentrated hydrochloric acid until

* *Bone* and *Sprankling*, J. C. S. 1899, 75, 845.
† *Ibid.* 853.

the oil has disappeared. On cooling, part of the methyl-succinic acid may separate and is collected with the aid of the pump, washed with concentrated hydrochloric acid, and crystallized from this solvent. The filtrate is made alkaline with concentrated ammonia, filtered from any silica which separates, and the clear solution boiled with excess of a 25 per cent solution of calcium chloride.* The insoluble calcium methyl-succinate is removed, washed with hot water, decomposed by dissolving in hot concentrated hydrochloric acid, and allowing to crystallize. After recrystallization from benzene it forms colourless needles, m.p. 111°. Yield, 56 per cent of theory, calculated from the cyanoacetate used.

Ethyl α-bromisobutyrate may be substituted for ethyl α-bromopropionate, but the mixture must then be heated at 100° for twenty-four hours in soda-water bottles corked and wired. The final product is *as*-dimethyl-succinic acid, m.p. 140–141°.

Condensation of ethyl malonate with an aldehyde, and formation of the ester of a tetrabasic acid.

$$CH_2{:}O + \begin{matrix} H\cdot CH(CO_2Et)_2 \\ H\cdot CH(CO_2Et)_2 \end{matrix} \rightarrow CH_2[CH(CO_2Et)_2]_2.$$

Experiment 256.—Glutaric acid.

(*a*) 5 g. of diethylamine are added to a mixture of 320 g. of ethyl malonate and 80 g. of 40 per cent formalin in a round-bottomed flask cooled to 5° by immersion in ice. The mixture is allowed to attain room temperature and is then kept at this temperature for 15 hours. The aqueous layer is separated and the residue distilled under reduced pressure. Yield of ethyl propane ααγγ-tetra-carboxylate, 250 g., b.p. 190–200°/12 mm. or 210–215°/20 mm.

(*b*) 125 g. of the above ester, 125 ml. of concentrated hydrochloric acid, and 125 ml. of water are heated for 6–8 hours in a reflux apparatus on an oil bath until the mixture becomes homogeneous. It is then evaporated to dryness and the residual glutaric acid distilled under reduced pressure. The fraction boiling at 185–195°/10 mm. is collected, moistened with water, and warmed gently to convert any anhydride into acid, and finally dried at 30° and crystallized from benzene. M.p. 96–97°. Yield, 38–40 g.

* To avoid bumping, the solution may be boiled by blowing steam through.

Michael's Reaction.*

An interesting reaction of sodio-ethyl malonate is the readiness with which it adds on to the double linkage in many olefine compounds, particularly $\alpha\,\beta$ unsaturated esters, nitriles or compounds with a strong negative group attached to one of the carbon atoms. A few drops of piperidine or diethylamine are generally added as a catalyst. The sodium becomes attached to the negative carbon atom and the $\cdot CH(CO_2Et)_2$ group to the other:

$$CHNa(CO_2Et)_2 + C_6H_5{\cdot}CH{:}CH{\cdot}CO_2Et \rightarrow \begin{array}{l} C_6H_5{\cdot}CH{\cdot}CHNa{\cdot}CO_2Et \\ \quad\quad\;\; \dot{C}H(CO_2Et)_2, \end{array}$$

and the product when hydrolysed gives the corresponding tribasic acid, which readily loses carbon dioxide, giving β-phenylglutaric acid, $CO_2H{\cdot}CH_2{\cdot}CHPh{\cdot}CH_2{\cdot}CO_2H$.

The reaction is a balanced one so that, as a rule, yields are not quantitative, but it is of value for the synthesis of polybasic acids.

Experiment 257.—β-Phenylglutaric acid from ethyl cinnamate and ethyl malonate.

2·3 g. sodium are dissolved in 25 ml. absolute ethyl alcohol and 16·0 g. of ethyl malonate, and 17·6 g. ethyl cinnamate added. The mixture is placed in a stout bottle with screw stopper and heated for 6 hours in a water bath which is gradually brought up to boiling. The alcohol is then removed by evaporation or distillation, the residual liquid poured into water, and the separated oil extracted with ether. After drying with calcium chloride the ethereal solution is fractionated, the triethyl ester distilling over at 305–310° with partial decomposition. It is purified by distillation under diminished pressure. B.p. (at 15 mm.), 213–215°.

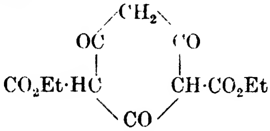
The ester is hydrolysed with excess of saturated barium hydroxide solution by heating in a water bath for several hours (until the oil disappears). On cooling, crystals of the barium salt separate, and the crystals and solution are acidified with hydrochloric acid, and the oily acid taken up with ether. After drying with anhydrous sodium sulphate the ether is distilled off, and the thick oil which remains heated in an oil bath at 110°, at which temperature rapid evolution of carbon dioxide occurs. The residue is crystallized from aqueous alcohol. Colourless crystals; m.p. 137–138°.

* J. pr. 1887, 35, 351.

Formation of Closed-Ring Derivatives from Ethyl Malonate

Experiment 258.—Ethyl phloroglucinol-dicarboxylate.* According to Moore the reaction proceeds as follows:

$3CH_2(CO_2Et)_2 + 2Na$

$=$  $+ 4EtOH + Na_2CO_3.$

3·6 g. of sodium are dissolved in 50 ml of absolute alcohol in a reflux apparatus, and when nearly cold, 50 g. of ethyl malonate are added. The mixture is transferred to a soda-water bottle or pressure flask and heated in a brine bath at 105–108° for fifteen hours. A white compound settles out, which consists of the sodium compound of ethyl phloroglucinol-dicarboxylate and sodium carbonate. The product is filtered with the aid of a pump, the precipitate washed with alcohol, then dissolved in water and decomposed by the gradual addition of dilute hydrochloric acid until acid. The precipitated ester solidifies to an almost white crystalline mass, which is filtered off and recrystallized from alcohol. It forms white crystals, m.p. 106–107°.

When hydrolysed with aqueous potassium hydroxide solution it yields phloroglucinol, $C_6H_6O_3$.

XXVI. REDUCTION. (S.B. Chap. XLVII)

A. Reduction in Acid Solution

The method in which a metal and acid are employed has been described in Exps. 150, 151, and the use of stannous chloride and hydrochloric acid in Exps. 195, 196, 199. Another type of acid reduction is by means of hydriodic acid in the presence of red phosphorus.

* *Baeyer*, B. 1885, **18**, 3457; *Moore*, J. C. S. 1904, **85**, 168.

Experiment 259.—Reduction of benzylic acid (diphenylhydroxyacetic acid) to diphenylacetic acid.*

$$(C_6H_5)_2C\begin{matrix}\diagup OH \\ \diagdown CO_2H\end{matrix} + 2H \rightarrow (C_6H_5)_2CH{\cdot}CO_2H + H_2O.$$

A solution of 25 g. of benzylic acid (Exp. 345) in 100 g. of glacial acetic acid is boiled with 7 g. of concentrated hydriodic acid and the same weight of red phosphorus for one hour in a round-bottomed flask provided with an upright air condenser. The hot solution is filtered, poured into water, and the precipitated diphenylacetic acid filtered with the aid of the pump, washed with water, and recrystallized from hot water or alcohol. The yield is practically theoretical, and the product forms colourless needles, m.p. 146°.

In many cases the reduction with hydriodic acid and red phosphorus can only be accomplished by heating the mixture in a sealed tube. In this way benzophenone, $C_6H_5{\cdot}CO{\cdot}C_6H_5$, is reduced to diphenyl-methane, $(C_6H_5)_2CH_2$, anthraquinone, $C_6H_4\begin{matrix}\diagup CO \diagdown \\ \diagdown CO \diagup\end{matrix}C_6H_4$, to dihydro-anthracene, $C_6H_4\begin{matrix}\diagup CH_2 \diagdown \\ \diagdown CH_2 \diagup\end{matrix}C_6H_4$, and many fatty acids to the corresponding paraffins.

The use of sulphurous acid as a reducing agent is described in Exp. 139, in the preparation of quinol from *p*-benzoquinone.

Clemmensen's Reduction Method.

A general method, known as the *Clemmensen method*, for reducing aldehydes or ketones to the corresponding hydrocarbons is by the use of amalgamated zinc and acid.†

Experiment 260.—*o*-Cresol from salicylaldehyde.

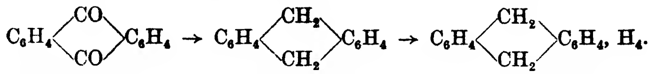
150 g. amalgamated zinc and 200 ml. concentrated hydrochloric acid are heated in a reflux apparatus on a water bath until vigorous evolution of hydrogen begins. 25 g. of salicylaldehyde are then added drop by drop through the condenser with additional hydrochloric acid if necessary. When the addition is completed, the mixture is heated for an hour and the product steam-distilled. The distillate is saturated with common salt and the *o*-cresol extracted with ether, dried with anhydrous sodium sulphate, and fractionated. B.p. 189°. Yield, 15 g.

* *Klingemann*, A. 1893, 275, 84.
† B. 1913, 1840; 1914, 51, 681.

Experiment 261.—Ethylbenzene from acetophenone.

100 g. of granulated zinc are added to 200 ml. of a 5 per cent aqueous solution of mercuric chloride. After an hour the solution is removed and 25 g. of acetophenone added to the residue with sufficient dilute hydrochloric acid (1 : 2) to cover the zinc. The whole is heated in a reflux apparatus during 6 hours, small amounts of acid being added at intervals. The oil is then steam-distilled, dried and fractionated; b.p. 136°. Yield, 70 per cent.

This method of reduction is of great value in reducing cyclic ketones, quinones and their hydroxy-derivatives to the corresponding hydrocarbons. Thus anthraquinone and its derivative, alizarin, are both reduced to hydrides of anthracene.



Anthraquinone — Anthracene dihydride — Anthracene hexahydride

Experiment 262.—Reduction of anthraquinone to dihydroanthracene.

100 g. of granulated zinc are treated as in Exp. 261 and covered with hydrochloric acid. 10 g. anthraquinone (Exp. 232) are rubbed into a thin paste with hydrochloric acid and added to the mixture in a reflux apparatus and heated for 3–4 hours. On cooling, white needle-shaped crystals are deposited which are taken up with alcohol and recrystallized. Yield, 80 per cent of theory; m.p. 107°.

B. Reduction in Alkaline Solution

(*a*) With sodium amalgam (see Chap. XXXVIII) and water, or sodium amalgam and sodium hydroxide solution.

Experiment 263.—Reduction of cinnamic acid to β-phenylpropionic acid (hydrocinnamic acid).

$$C_6H_5{\cdot}CH{:}CH{\cdot}CO_2H + 2H \rightarrow C_6H_5{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H.$$

15 g. of cinnamic acid (Exp. 284) are dissolved in the requisite amount of sodium hydroxide solution, and the solution transferred to a separating funnel, which is placed in a bath so that it can be kept at about 30–35°. 200 g. of 2·5 per cent sodium amalgam are added in small portions, and the mixture well shaken after each addition. The whole opera-

tion should be completed in about thirty minutes. At the beginning the amalgam liquefies rapidly, very little hydrogen is evolved, and the solution becomes warm. Towards the end the amalgam does not liquefy at all readily, and numerous bubbles of hydrogen are evolved. After standing for an hour the mercury is drawn off by means of the tap, and the alkaline liquid poured into an excess of moderately concentrated hydrochloric acid. The hydrocinnamic acid separates as an oil, but quickly solidifies. It may be crystallized from a large volume of warm water or from light petroleum (b.p. 35–40°), but in the latter case must be dried before dissolution in the solvent. It forms colourless needles, m.p. 47·5°. Yield, 90 per cent of theory.

Most $\alpha\beta$ unsaturated acids may be reduced by this method, but $\beta\gamma$ unsaturated acids, e.g. $C_6H_5{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CO_2H$, are not reduced readily by sodium amalgam and water.

Acids containing two double bonds, one in the $\alpha\beta$ and the other in the $\gamma\delta$, usually add on hydrogen in the $\alpha\delta$ (1 : 4) positions, and yield a $\beta\gamma$ unsaturated acid:

$$C_6H_5{\cdot}CH{:}CH{\cdot}CH{:}C(CO_2H)_2 \rightarrow C_6H_5{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH(CO_2H)_2.$$

Thus both cinnamylidene-acetic and cinnamylidene-malonic acids (Exp. 287) when reduced in this way yield $\beta\gamma$ unsaturated acids.

(*b*) With sulphuretted hydrogen in the presence of alcoholic ammonia (see Exp. 152).

(*c*) With metallic zinc, i.e. zinc dust, in the presence of sodium hydroxide solution.

Experiment 264.—*sym*-**Diphenyl-hydrazine (hydrazobenzene) from azobenzene.**

$$C_6H_5{\cdot}N{:}N{\cdot}C_6H_5 + 2H \rightarrow C_6H_5{\cdot}NH{\cdot}NH{\cdot}C_6H_5.$$

A solution of 10 g. of azobenzene (Exp. 270) in 100 ml. of alcohol is added to 16 g. of sodium hydroxide solution (25 per cent), and the mixture heated in a round-bottomed flask fitted with a reflux condenser. After the addition of 15 g. of zinc dust in small portions the solution should be colourless, and may then be filtered, as rapidly as possible by means of the pump, into a dilute solution of sulphurous acid. As the solution cools the hydrazobenzene crystallizes in colourless plates. These are filtered, washed with a little sulphurous acid, dried, and recrystallized from light petroleum. M.p. 131°.

In the moist state it is readily oxidized in contact with the air, hence care is required in filtering and drying.

(*d*) The conversion of aromatic nitro-derivatives into azoxy-compounds when boiled with sodium methoxide.

$$4R{\cdot}NO_2 + 3NaOCH_3 \rightarrow 2\underset{\underset{O}{\vee}}{RN{\cdot}NR} + 3H{\cdot}CO_2Na + 3H_2O.$$

Experiment 265. — Azoxybenzene, $C_6H_5{\cdot}N_2O{\cdot}C_6H_5$, **from nitrobenzene.***

Sodium methoxide is prepared by dissolving 20 g. of metallic sodium in 200 g. of absolute methyl alcohol contained in a litre round-bottomed flask fitted with a reflux condenser through which a rapid stream of water is passing. The sodium should be quite clean, and may be dropped through the condenser tube in quantities of 2–3 g. at a time. A vigorous action occurs, and fresh metal is added when the previous lot has dissolved. When all the sodium has been added 30 g. of nitrobenzene are run in, and the whole is boiled on the water bath for three to four hours. As the reaction proceeds sodium formate crystals are deposited, and may produce bumping. The excess of methyl alcohol is removed by distillation, the flask being immersed in boiling water; and the residue is mixed with water in a beaker, when a dark oil separates, which, however, solidifies rapidly to a hard cake. This cake is washed several times with water, and pressed on a porous plate. Yield, 23 g. When dry it may be crystallized from light petroleum, and is deposited in the form of yellow needles, m.p. 36°.

(*e*) A method of considerable value in obtaining alcohols difficult to prepare by other methods is by the *Bouveault and Blanc method* † of reducing esters with metallic sodium and ethyl or amyl alcohol. It is an indirect method of converting a ·CO·OH group to the $\cdot CH_2 \cdot OH$ group. The yields are often quite good, especially with esters of fatty acids, but the method does not work with esters of the benzoic series or esters of α-hydroxy acids. If much hydrolysis of the ester occurs, the yields are poor and hence phenyl or naphthyl esters, which are difficult to hydrolyse, are sometimes used. For good yields the reduction should take place rapidly.

* *Klinger*, B. 1882, **15**, 865.

† Bull. Soc. 1904, **31**, 669.

Experiment 266.—Lauryl alcohol from ethyl laurate.*

$$CH_3(CH_2)_{10}{\cdot}CO_2Et \rightarrow CH_3(CH_2)_{10}{\cdot}CH_2OH.$$

A 2·5 litre round-bottomed flask is used and is provided with a stopper with three holes. The middle one carries the mechanical stirrer with a mercury seal, another carries a long, wide reflux water condenser (the inner tube should be 2 m. long and 2·5 cm. diameter), and the third hole carries a dropping funnel. The flask containing 35 g. of finely divided sodium and 100 ml. of dry toluene † is warmed on the water bath to 60°. From the dropping funnel is run in a solution 57 g. of ethyl laurate in 75 ml. water-free alcohol,‡ then 250 ml. more alcohol as rapidly as possible, but without losing material through the condenser. If there is a tendency for the reaction to become too vigorous and eject sodium through the condenser, the flask is cooled by a mixture of ice and water. The addition should not take more than 3–4 minutes. When the reaction has subsided, the flask is heated on a water bath until the sodium is completely dissolved. The mixture is then steam-distilled to remove toluene and alcohol, and the residue transferred hot to a separating funnel, in which it is washed three times with 100 ml. portions of hot water to remove sodium laurate. The lauryl alcohol is extracted from the cold mixture and the washings by ether. The ethereal extract is washed with water, then with sodium carbonate solution and again with water; it is finally dried over anhydrous magnesium sulphate. After removal of the ether the lauryl alcohol is distilled under reduced pressure. Yield, 30–35 g.; b.p. 143–146°/18 mm., or 198–200°/135 mm.

Ethyl undecylenate, ethyl myristate and ethyl palmitate may be reduced in the same manner to the corresponding alcohols.

C. Reduction in Neutral Solution

(*a*) By the copper-zinc couple (see Exp. 14).

(*b*) When magnesium amalgam is substituted for sodium amalgam the solution is practically neutral and the reduction

* Chem. Synth. 1930, **10**, 62.

† Chap. XXXVIII.

‡ Finally dehydrated by magnesium methoxide, $Mg(OMe)_2$.

of acetone with magnesium amalgam is the best method for obtaining good yields of the glycol pinacol.

$$2CH_3{\cdot}CO{\cdot}CH_3 + 2H \rightarrow OH{\cdot}C(CH_3)_2{\cdot}(CH_3)_2{\cdot}OH.$$

Experiment 267.—Pinacol * from acetone.

20 g. of magnesium turnings and 200 ml. of dry benzene are placed in a 1·5 litre flask provided with an efficient reflux condenser and a dropping funnel. A solution of 22·5 g. of mercuric chloride in 100 ml. of dry acetone is added from the dropping funnel, at first very slowly, then, when the reaction has begun, more quickly, so that the reaction proceeds as rapidly as possible without loss of acetone through the condenser. As soon as the reaction subsides a mixture of 50 ml. of benzene and 50 ml. of acetone is added and the whole heated in a water bath for 2 hours. The solid magnesium salt of pinacol is broken up and the heating continued for an hour. 50 ml. of water are added and the mixture heated for an hour on the water bath, then cooled to 50° and filtered. The solid is extracted with 125 ml. of hot benzene to dissolve pinacol. The combined filtrate and extract is distilled to about one-third of its volume to remove acetone, and the benzene solution so obtained is mixed with 75 ml. water and cooled to 10–15°. Pinacol hydrate separates. Yield, 80 g. It can be purified by crystallization from an equal weight of boiling water.

(*c*) Another reduction which may be regarded as occurring in aqueous solution is by the action of aluminium ethoxide in the presence of alcohol, and the reaction is of value for reducing aldehydes and ketones,

$$\underset{\text{(As aluminium compound)}}{R{\cdot}CH{:}O + CH_3{\cdot}CH_2{\cdot}OH} \rightleftharpoons R{\cdot}CH_2{\cdot}OH + CH_3{\cdot}CH{:}O.$$

As the reaction is reversible it is advisable to work in the presence of an appreciable excess of ethyl alcohol or at a temperature sufficiently high to remove the acetaldehyde as fast as it is formed.

Experiment 268.—Furfuryl alcohol from furfuraldehyde.

Reduction of furfuraldehyde.—A mixture of freshly distilled furfuraldehyde (100 g.), alcohol (235 ml.), and aluminium ethoxide (Chap. XXXVIII) (30 g.) is kept at 25° for about 5 days until the furfuraldehyde has disappeared.† The solvent

* Frequently called pinacone—Org. Syn., 5, 87.

† Test with aniline acetate.

is removed, the last traces by heating in a bath at 120°. The residue is steam-distilled, the distillate saturated with sodium carbonate and extracted with ether. After drying and removing the ether the furfuryl alcohol is obtained as a colourless liquid, b.p. 172–173°. Yield, 90 g.*

A similar method may be used for reducing ketones and has the advantage that if an unsaturated ketone is used, only the carbonyl group is affected, the olefine linkage remaining intact. Similarly halogen and nitro-groups in the aldehyde or ketone are not reduced.

A method of reduction similar to that just described is the use of alcoholic solution of ethoxy magnesium chloride, EtO·Mg·Cl, obtained by heating magnesium with absolute alcohol and sufficient hydrogen chloride to yield the mixed chloride.†

(*d*) By zinc dust and water, e.g. the reduction of an aromatic nitro-derivative to the corresponding hydroxylamine.

Experiment 269.—Phenyl-hydroxylamine from nitrobenzene.‡

$$C_6H_5{\cdot}NO_2 + 4H \rightarrow C_6H_5{\cdot}NH{\cdot}OH + H_2O.$$

Warning.—Warm solutions of phenyl-hydroxylamine produce wounds, and the dry powder causes violent sneezing. The operations should be conducted in a good fume cupboard.

A mixture of 12 g. of nitrobenzene (freshly distilled) (Exp. 113) and 250 ml. of water containing 6 g. of ammonium chloride is well agitated by an automatic stirrer in a stout glass beaker which is surrounded by cold water, so that the temperature is kept below 15°. 18 g. of zinc dust (75 per cent, or an equivalent amount of a less active dust) are added in four equal parts after intervals of a quarter of an hour. The stirring is continued until the odour of nitrobenzene has disappeared; this should take some 10 minutes after the addition of the last portion of zinc dust. The mixture is then filtered by means of the pump and a Buchner funnel. The precipitate of zinc and hydroxide is washed by adding about 200 ml. of water at 45° when the pump is not working; the water is then slowly sucked through by means of the pump, and the precipitate ultimately pressed together and sucked as dry as possible.

It is an advantage to keep the main filtrate separate from

* *Meerwein* and *Schmidt*, A. 1925, **444**, 221.

† *Meerwein* and *Schmidt*, loc. cit. p. 236.

‡ D. R. P. 89978, also *Gattermann*, Prax. Org. Chem. 194.

the washings. The two solutions are separately saturated with finely powdered pure sodium chloride (about 70 and 55 g. respectively), and are then cooled to 0°. After some 15 minutes colourless crystals of phenyl-hydroxylamine separate. These are filtered, and dried on a porous plate without washing. Yield is practically theoretical. A small portion is crystallized from benzene and is obtained as colourless crystals; m.p. 81°. The remainder may be used for the preparation of nitrosobenzene (Exp. 277).

The β-aryl-hydroxylamines are good reducing agents: they readily reduce Fehling's solution and ammoniacal silver nitrate solution, and hence the formation of a hydroxylamine derivative may be used for the detection of NO_2 radicals in aromatic compounds (Chap. XV, C).

β-aryl-hydroxylamines are unstable in the presence of mineral acids, and undergo molecular rearrangement to *p*-aminophenols.

D. Reduction by Heating with a Metal

Oxygen is frequently removed when a compound is heated with a metal, such as zinc or iron.

Experiment 270.—Azobenzene from azoxybenzene.*

$$C_6H_5{\cdot}N_2O{\cdot}C_6H_5 + Fe \rightarrow C_6H_5{\cdot}N{:}N{\cdot}C_6H_5 + FeO.$$

15 g. of iron filings, which have been freed from oil by washing with alcohol and ether, and subsequently dried in the steam oven, are well mixed in a mortar with 5 g. of crystallized and dried azoxybenzene (Exp. 265), and the mixture transferred to a small non-tubulated retort and then carefully heated, the whole mass being evenly heated by moving the flame. The temperature is gradually raised until no more distillate passes over. The distillate is collected in a small porcelain dish, and solidifies to a bright-red crystalline mass. It is well pressed on a porous plate to remove oily impurities, and crystallized from light petroleum (b.p. 45–50°), in which it is readily soluble. It forms compact red plates, m.p. 68°.

Azobenzene can be obtained in two geometrical isomeric forms.†

Ph·N	Ph·N
Ph·N̈	N̈·Ph
syn-	*anti-*

* *Mitscherlich*, A. 1834, 12, 311. † *Hartley*, J. C. S. 1938 633; 1939, 232.

Experiment 271.—Anthracene from anthraquinone.

1 g. of anthraquinone (Exp. 232) is mixed with 5 g. of zinc dust and the mixture placed in the end of a hard glass test tube; 15 g. of zinc dust are added, and the tube is placed in a horizontal position and heated, beginning at the open end. Crystals of anthracene are deposited in the front part of the tube, and may be purified by sublimation; m.p. 213°. For further recognition prepare a specimen of the additive compound with picric acid.

E. Catalytic Reduction: Hydrogenation

Many compounds containing olefine, acetylene or carbonyl linkages can be reduced by gaseous hydrogen in the presence of a suitable catalyst. The two most frequently used on the small scale in the laboratory are (*a*) colloidal palladium or platinum deposited on a finely divided material, usually active charcoal (norite), (*b*) metallic nickel in a fine state of division or as Raney nickel.

The reduction with palladium is carried out in the liquid phase, whereas with nickel either the gaseous or liquid phase may be used. The palladium-norite process is the one usually employed for determining the degree of unsaturation of a compound, i.e. the number of olefine or acetylene linkages in the compound. As a rule when several olefine linkages are present the reduction proceeds in distinct stages according to the number of linkages present, the first stage taking place most rapidly. With an acetylene linkage the addition of the first two hydrogen atoms takes place more rapidly than that of the second pair.

Experiment 272.—Hydrogenation of olive oil.

The experiment consists essentially in reducing the glyceryl trioleate (triolein), $C_3H_5(O{\cdot}CO{\cdot}C_{17}H_{33})_3$, which is the chief constituent of olive oil, to glyceryl stearate, $C_3H_5(O{\cdot}CO{\cdot}C_{17}H_{35})_3$. Thus each molecule of triolein requires six atoms of hydrogen for complete reduction. Small amounts of the glyceryl esters of more highly unsaturated acids, e.g. linolic and linolenic, are reduced at the same time.

200 g. of acid-free oil and 9 g.* nickel kieselguhr catalyst

* As a rule 1 g. of nickel per 100 g. of oil is used.

(Chap. XXXVIII) are placed in a round-bottomed flask with a short neck provided with a 3-holed rubber stopper. The hydrogen inlet tube passes well into the oil-catalyst mixture but must be quite clear of the stirrer, which passes through the middle hole in the stopper and should reach well under the liquid. The third hole carries the hydrogen exit tube. The flask is placed in an asbestos air bath which is heated by a ring burner. The flask is filled with hydrogen at room temperature. The temperature is then raised to 180° and the stirrer started. The course of the reduction can be followed by taking samples of the oil at the beginning, and after definite intervals of time, and determining the refractive index at 60° with the aid of an *Abbé refractometer.* The value for pure glyceryl stearate is 1·4468 and as soon as the value approximates to this, e.g. 1·4472, the reduction may be regarded as complete. The flame is removed and the flask allowed to cool somewhat in a current of hydrogen. The solution is then filtered on a porcelain funnel to remove the catalyst. On cooling, the filtrate sets to a solid mass and can be used (*a*) for the preparation of stearic acid by hydrolysis, (*b*) for the preparation of ethyl stearate by alcoholysis. Melting-point of pure glyceryl stearate (tristearin) is 72°.

Experiment 273.—Allocinnamic acid from phenyl-propiolic acid.

Apparatus is set up as in fig. 91. A 500 ml. gas burette A holds and measures the hydrogen, and the solution to be hydrogenated is placed in a bottle connected to the burette by pressure tubing. The bottle is placed in a mechanical shaking machine. C is attached to a hydrogen cylinder and B to a vacuum pump.

2·92 g. of phenyl-propiolic acid (0·02 mol) and its equivalent weight of sodium carbonate are dissolved in 100 ml. of water and placed in the bottle with 0·5 g. of palladium catalyst (Chap. XXXVIII), which is then closed and clipped off from the burette. The burette is then nearly filled with hydrogen, its upper tap closed, the bottle and connexions filled with hydrogen, and evacuated twice in order to remove all air. The bottle is finally filled with hydrogen, the levels adjusted, the initial reading of the burette noted, and the shaker put in motion. The diminution in volume of the hydrogen in the burette corresponds to the volume absorbed. The volume of hydrogen required (about 450 ml.) at the temperature and pressure pre-

vailing should be accurately calculated and the experiment stopped when this volume has been absorbed.

The catalyst is removed by filtration, the filtrate acidified and the product extracted with ether. The ethereal solution

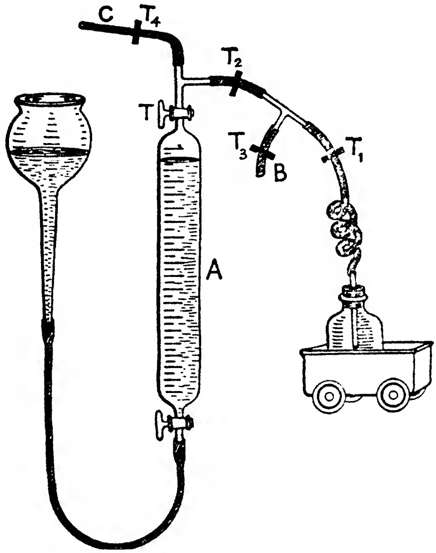


Fig. 91

is dried with anhydrous sodium sulphate and allowed to crystallize. Yield, 90 per cent; m.p. 57° or 68° according to conditions of crystallization.

Allocinnamic acid is trimorphous and can be obtained in three crystalline forms.

F. Electrolytic Reduction

As pointed out in S.B. Chap. XLVII, D, the products obtained in the case of electrolytic reduction depend not merely on the original materials, but also to a large extent on the conditions of electrolysis, e.g. nature of solvent, nature of electrodes, current density, and temperature.

Experiment 274.—Reduction of nitrobenzene to *p*-amino-phenol.*

$$C_6H_5{\cdot}NO_2 + 4H \rightarrow OH{\cdot}C_6H_4{\cdot}NH_2 + H_2O.$$

30 g. of nitrobenzene, 280 ml. of concentrated sulphuric acid, and 4–6 ml. of water are placed in a beaker which serves as the cathode compartment. The anode compartment consists of a porous cell containing concentrated sulphuric acid. The anode consists of a coil of stout platinum wire or of a cylinder of platinum foil. The cathode consists of a similar coil or cylinder wound round the porous cell. An E.M.F. of 7–8 volts and a C.D.† of 5–6 amperes is employed. The temperature rises to 75–80° during the electrolysis, but should not be allowed to rise beyond 85°, as sulphonation can then occur. After 30 ampere hours the reduction is complete, the current is stopped, and the cathode liquid cooled by means of a freezing mixture. Crystals of *p*-amino-phenol separate, and are filtered at the pump, using a glass funnel and plug of glass wool. They are pressed on a porous plate, and finally recrystallized from alcohol. Yield, 20–30 per cent of theory.

An 80 per cent sulphuric acid may be employed if the cathode is rapidly rotated.

The nitrobenzene is probably first reduced to phenyl-hydroxylamine, but as this is unstable in the presence of acids it is converted into the isomeric *p*-amino-phenol.

$$C_6H_5{\cdot}NH{\cdot}OH \rightarrow OH{\cdot}C_6H_4{\cdot}NH_2.$$

XXVII. OXIDATION

A considerable variety of reagents is available for oxidizing organic compounds. Many of these are to a large extent specific in their action, but an alteration of conditions may lead to a different type of reaction.

A. With Potassium Permanganate
(S.B. Chap. XLVIII. A)

(*a*) **In Alkaline Solution.**—In the presence of alkali a molecule of potassium permanganate can yield three atoms of

* *Gattermann*, B. 1893, **26**, 1846. † C.D. is current density per sq. dm.

oxygen for oxidation purposes according to the equation,

$$K_2Mn_2O_8 + H_2O \rightarrow 2KOH + 2MnO_2 + 3O.$$

An example of its action has already been given in Exp. 57. An important application is due to Fittig, who showed that in dilute solution the reagent oxidizes a compound containing an ethylene linkage to a dihydroxy-derivative, e.g.

$$C_6H_5 \cdot CH{:}CH \cdot CO_2H + H_2O + O \rightarrow C_6H_5 \cdot CH(OH) \cdot CH(OH) \cdot CO_2H.$$

N.B.—If a stronger solution is used, the molecule of the unsaturated compound is ruptured, and acids containing a smaller number of carbon atoms are formed. An examination of such oxidation products affords valuable evidence as to the position of the double bond in the original ethylene compound (S.B. Chap. VI, B).

Experiment 275.—Phenyl-dihydroxy-propionic acid (phenyl-glyceric acid),* $C_6H_5 \cdot (CH \cdot OH)_2 \cdot CO_2H$, from cinnamic acid.

10 g. of cinnamic acid (Exp. 284) are dissolved in dilute sodium hydroxide, and the solution made up to 1 litre. The solution is placed in a vessel surrounded by ice, and vigorously agitated by means of a mechanical stirrer, while a solution of 15 g. of potassium permanganate in 750 ml. of water is added gradually by means of a tap funnel. When the addition is completed the liquid is filtered from the precipitated hydrated manganese dioxide and concentrated to half its volume. Any benzaldehyde present is carried away with the steam. The residue is neutralized by the addition of concentrated hydrochloric acid, and evaporated on a water bath until the dissolved salts begin to separate. More concentrated hydrochloric acid is added, and the product extracted several times with large quantities of ether. This is necessary because the chief product of oxidation (phenyl-glyceric acid) is only sparingly soluble in ether while readily soluble in water. The ethereal solution is evaporated, and the residue recrystallized from hot benzene or ether.

It consists of white glistening needles, m.p. 141–142°; is readily soluble in water, sparingly in ether, insoluble in cold but sparingly soluble in hot benzene.

(*b*) **In Neutral Solution.**—The permanganate is sometimes used in neutral solution; in order to remove the potassium hydroxide formed during its decomposition, excess of magnesium sulphate is added at the beginning.

* *Fittig* and *Ruer*, A. 1892, 268, 27.

Experiment 276.—Acetanthranilic acid,* $CO_2H{\cdot}C_6H_4{\cdot}NH{\cdot}CO{\cdot}CH_3$, **from acet-*o*-toluidide,** $CH_3{\cdot}C_6H_4{\cdot}NH{\cdot}CO{\cdot}CH_3$.

10 g. of acet-*o*-toluidide (Exp. 168) and 20·6 g. of magnesium sulphate crystals are dissolved in 1200 ml. of water in a large beaker fitted with a mechanical stirrer and thermometer. The mixture is heated to 75–80°, and then 29·2 g. of potassium permanganate are added. The liquid is stirred vigorously until all the permanganate has disappeared, the temperature during this process being maintained at 85°; this takes about one and a half hours. The hot solution is then filtered, and the clear filtrate acidified with dilute sulphuric acid. A colourless precipitate is obtained, which is filtered off and washed with a little water. Yield, 75 per cent of theory. M.p. 185°.

(*c*) **In Acid Solution.**—In the presence of mineral acid, a molecule of potassium permanganate can yield five atoms of oxygen for oxidation purposes. The mixture is a powerful oxidizing agent, and is only used for the preparation of very stable organic compounds (cf. S.B. Chap. XLVIII, A).

B. Chromic Acid Derivatives

Chromic anhydride, CrO_3, is generally used in acetic acid solution (cf. Exp. 232).

Chromyl chloride, CrO_2Cl_2, oxidizes benzene hydrocarbons to aldehydes (Etard's reaction) (cf. Exp. 204).

The usual method of using chromic acid is in the form of a mixture of a dichromate and sulphuric acid. Examples of its use have been met with in Exps. 171 and 200.

A further example is the oxidation of phenylhydroxylamine to nitrosobenzene.

$$C_6H_5{\cdot}NH{\cdot}OH + O \rightarrow C_6H_5{\cdot}N{:}O + H_2O.$$

Experiment 277.—Oxidation of phenylhydroxylamine to nitrosobenzene.†

An ice-cold solution of 4·6 g. of potassium dichromate in 200 ml. of water is added rapidly to a freshly prepared mixture of finely divided phenylhydroxylamine (Exp. 269) (4 g.), concentrated sulphuric acid (30 g.), and water (270 g.), also cooled by ice water. Nitrosobenzene separates, and is removed

* D. R. P. 94, 629. † D. R. P. 89, 978, *Wohl* and *Bamberger*.

by immediately subjecting the mixture to steam distillation, when the nitrosobenzene passes over as green oily drops which solidify in the condenser to colourless crystals. These are removed, pressed on a porous plate, and washed with a little low-boiling light petroleum. It melts at 67·5–68° to a deep-green liquid.

C. Nitric Acid

One of the chief drawbacks to the use of this reagent for oxidation is that it is also a nitrating agent (cf. Chap. XV). An example of its oxidizing power has been given in Exp. 68; the following experiment illustrates its use in oxidizing a secondary alcoholic group to a ketonic group.

Experiment 278.—Benzil,* $C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5$, **from benzoin,** $C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5$.

15 g. of benzoin (Exp. 211) are heated with 35 g. of concentrated nitric acid (sp. gr. 1·4) in a small flask on a boiling-water bath for 1½–2 hours. The product is poured into cold water, and the mass which solidifies is washed several times with cold water, dried on a porous plate, and recrystallized from alcohol. Yield, 90 per cent of theory.

Benzil crystallizes in well-developed yellow prisms, m.p. 95°. It is a diketone and yields two monoximes and three dioximes.

Nitrobenzene is sometimes used as an oxidizing agent, cf. Skraup Synthesis (Exp. 295).

D. Sulphuric Acid

An example at one time of commercial importance is the oxidation of naphthalene by means of sulphuric acid to phthalic acid (Exp. 58).

E. Peroxides

Lead dioxide is used for oxidizing leuco-bases to dye-bases (Exp. 307). Its derivative, **lead tetracetate,** $Pb(O{\cdot}CO{\cdot}CH_3)_4$, is used for the preparation of glycol diacetates from olefine compounds.†

Manganese dioxide in the presence of sulphuric acid is largely used for the oxidation of benzene homologues to aldehydes,

* *Zinin*, A. 1840, **34**, 188.

† *Dimroth* and *Schweitzer*, B. 1923, 1384.

using an excess of the hydrocarbon and constantly stirring the mixture.

Hydrogen peroxide, perhydrol, acts in a manner similar to that of alkaline permanganate and forms dihydroxyl derivatives of unsaturated acids and esters (cf. Exp. 275).*

F. Organic Per-Acids

The organic per-acids—perbenzoic $C_6H_5\cdot CO\cdot O_2H$ and peracetic $CH_3\cdot CO\cdot O_2H$—act on ethylene compounds to form compounds of ethylene oxide type, e.g.

$$\underset{\text{Styrene}}{C_6H_5\cdot CH:CH_2} \rightarrow C_6H_5\cdot \underset{\diagdown O \diagup}{CH\cdot CH_2}.$$

Experiment 279.—Styrene oxide from styrene.†
10 g. of styrene (Exp. 298) are added to a solution of 15 g. of perbenzoic acid in 150 ml. of chloroform, the mixture shaken and then kept for a day or longer. The solution is then extracted with 10 per cent sodium hydroxide solution (to remove benzoic acid), washed with water, dried over anhydrous sodium sulphate, and fractionally distilled. Yield, 8 g.; b.p. 188–192°.

G. Ozone

When ozonized oxygen or air is passed into a solution of an unsaturated compound in a non-aqueous solvent, a molecular proportion of ozone is taken up at one or more double bonds with the formation of an unstable product called an **ozonide**. If the original compound also contains an aldehydic or carboxylic group, an additional atomic proportion of oxygen may be taken up with the formation of an **ozonide-peroxide.**

Such products may be isolated, generally as gummy residues, by careful evaporation of the solvent *in vacuo*. They are unstable and sometimes explosive and consequently their isolation is not advisable. Ozonide-peroxides generally lose their peroxide oxygen by treatment with cold water, hydrogen peroxide being formed, while the ozonides are decomposed by

* *Hilditch*, J. C. S. 1926, 1833.
† *Hibbert* and *Burt*, J. A. C. S. 1925, 2243.

boiling with water, with the formation of aldehydes, ketones, and carboxylic acids, e.g.

$$\underset{\text{Oleic acid}}{CH_3(CH_2)_7\cdot CH{:}CH\cdot(CH_2)_7CO_2H} \rightarrow \underset{\text{Oleic acid Ozonide-peroxide}}{CH_3(CH_2)_7\cdot \underset{\diagdown O_3 \diagup}{CH{-}CH}\cdot(CH_2)_7CO_2H.}$$

$$\rightarrow \underset{\text{Nonaldehyde}}{CH_3(CH_2)_7\cdot CHO} \;:\; \underset{\text{Nonenic acid}}{CH_3(CH_2)_7CO_2H} \;;\; \underset{\text{Azeleic acid semialdehyde}}{CHO(CH_2)_7CO_2H}$$

$$:\; \underset{\text{Azeleic acid}}{CO_2H(CH_2)_7CO_2H.}$$

If the unsaturated compound is ozonized in aqueous solution or suspension the oxidation proceeds to an end in one stage. Thus maleic acid when ozonized in aqueous solution yields glyoxilic acid which can be separated as its phenylhydrazone.

$$CO_2H\cdot CH{:}CH\cdot CO_2H + O_3 + H_2O \rightarrow H_2O_2 + 2CHO\cdot CO_2H.$$

Experiment 280.—Glyoxilic acid from maleic acid.*

2 g. maleic acid are dissolved in 10 ml. water in a small wash bottle and ozonized oxygen bubbled through for 2 hours. The resulting solution is treated with a solution of 4 g. of phenylhydrazine in 10 ml. of 50 per cent acetic acid, warmed for a few minutes, cooled, and the crystallized glyoxilic acid phenylhydrazone filtered. Yield, 1·5 g.; m.p. 144°.

Experiment 281.—Nonaldehyde and azeleic acid from sodium oleate.†

5 g. of sodium oleate are dissolved in 100 ml. water, the solution filtered into a suitable wash bottle and ozonized oxygen passed through for 5 hours. The resulting milky suspension is subjected to distillation under low pressure when the aldehyde passes over with water. The distillate is extracted with ether, the extract dried with calcium chloride, the ether removed, and the non-aldehyde distilled under reduced pressure. B.p. 80–85°/15 mm.; yield, 2 g.; semicarbazone, m.p. 84°; 2:4-dinitrophenylhydrazone, m.p. 96°.

The aqueous solution left in the distilling flask contains the sodium salts of the three acids, the main constituent being azeleic acid. The semi-aldehyde is oxidized by the gradual addition of potassium permanganate solution (1 per cent) until there is no further decolorization and then acidified with dilute sulphuric acid. The precipitated acid is crystallized from dilute alcohol. Yield, 2·5 g.; m.p. 106°.

* *Harries*, B. 1903, **36**, 1933. † *Thieme*, A. 1905, **343**, 354.

H. Catalytic Oxidation. Dehydrogenation

Many metals in the form of wire or coarse powder catalyse the oxidation of many carbon compounds by air or oxygen (cf. Exp. 201).

The proportion of hydrogen in a compound may be decreased in many cases by heating the compound with certain elements which readily form hydrides. For this purpose sulphur has been found to be suitable, and has been used for the conversion of sesquiterpenes into the corresponding naphthalene derivatives, e.g. cadinene and zingiberine $C_{15}H_{24}$ both yield cadalene $C_{15}H_{18}$, a dimethylisopropyl-naphthalene. More recently the element selenium has replaced sulphur as an agent for dehydrogenation.*

The original application of this technique was due to Vesterberg, who converted abietic acid (a diterpene derivative) to retene (1-methyl-7-isopropylphenanthrene).†

$$C_{20}H_{30}O_2 + 5S \rightarrow C_{18}H_{18} + CO_2 + CH_3SH + 4H_2S.$$

Experiment 282.—Retene from abietic acid.

50 g. of abietic acid are intimately mixed with 25 g. of flowers of sulphur and placed in a retort which is attached to a distilling flask as receiver. The retort is heated in a paraffin or metal bath. At 200° rapid evolution of hydrogen sulphide occurs; when this moderates the temperature of the bath is raised to 250°, the side tube of the distillation flask attached to a pump and the distillation continued under low pressure (20 mm.). The temperature is then maintained at 260–270° as long as any product passes over, and the neck of the retort warmed so as to drive this into the receiver.

A yellowish crystalline mass is obtained (11–12 g.) which is taken up with ether and shaken with sodium hydroxide solution to remove acid impurities. The ether is removed and the residue dissolved in alcohol, any insoluble matter being rejected. On evaporation the alcoholic solution yields tabular crystals of retene, m.p. 98–99°. Yield, 3 g.

The hydrocarbon yields a crystalline picrate (m.p. 115°) and a compound with 1:3:5-trinitrobenzene; m.p. 139°.

Note.—Abietic acid is a constituent of colophony (rosin),

* *Ruzicka*, Helv. Chim. Acta, 1921, 505 *et seq.*

† *Vesterberg*, Ber. 1903, 4200.

from which it can be extracted by digestion with alcohol and subsequent recrystallization of the crude product. M.p. 150–152°.

J. Electrolytic Oxidation

(S.B. Chap. XLVIII, I)

The method is not so general in application as electrolytic reduction, as it is difficult to gauge the end of the reaction.

Experiment 283.—Bromoform, $CHBr_3$, **from acetone.***

60 g. of potassium bromide and 0·3 g. of potassium chromate are dissolved in 150 ml. of water, and 20 ml. of acetone are added to the solution.

The electrolysing cell is a beaker of 200 ml. capacity, the anode, consisting of a sheet of platinum of 50 sq. cm. area, bent so as to fit closely to the wall of the beaker. The cathode, consisting of a stout platinum wire in the form of a spiral, is fixed in the centre of the cell.

A current of 3 amperes is passed through the solution (E.M.F. 4–4·2 volts) for 4–5 hours. In order that the temperature shall not rise above 20° the beaker is placed in a bath of cold water. To remove the potassium hydroxide formed at the cathode, a rapid current of carbon dioxide from a Kipp's generator is bubbled through the liquid.

The bromoform, which settles at the bottom of the beaker, is strongly coloured with bromine. The oily bromoform is removed with the aid of a separating funnel, and is then shaken with a mixture of dilute sodium carbonate solution and acetone until the brown colour disappears. It is finally washed with water, dried over calcium chloride, and distilled. M.p. 7·6°; b.p. 151°.

XXVIII. POLYMERIZATION AND CONDENSATION

The term *polymerization* usually denotes the union of two or more molecules of a relatively simple compound to form a more complex entity without the elimination of water or any other simple substance. The polymer has the same percentage

* *Muller* and *Loebe*, Z. E., 1904, **10**, 409.

composition as the original compounds but its molecular weight is a multiple of that of the monomer.

Under the term *condensation* is understood a reaction in which two or more molecules react, forming a more complex compound with the elimination of water, halogen hydracid, ammonia, alcohol, &c. The products have a composition different from those of the originals. Many of the reactions dealt with in previous chapters are strictly condensations, e.g. esterification, but are not grouped as such.

Both polymerizations and condensations are divided into simple polymerizations and condensations, and long chain polymerizations and poly-condensations when the number of molecules involved is large. The latter type can yield products of great commercial value, e.g. some of the more important plastics manufactured on a large scale.

The reagents most commonly used to bring about polymerization or condensation are: sulphuric acid, hydrogen chloride, alkalis, sodium ethoxide, stannic chloride, antimony pentachloride, potassium cyanide, zinc chloride, aluminium chloride, ammonia, amines, particularly piperidine, pyridine, quinoline, dimethylaniline, organic peroxides and copper bronze. In many cases the reagent acts as a catalyst and only small amounts are required.

A. Simple Polymerizations

A number of these have already been described, e.g. para- and meta-acetaldehyde (Exp. 180), benzoin (Exp. 211), aldol (Exp. 210), diacetone alcohol (Exp. 219), pinene-nitrosochloride (Exp. 51). None of these involves more than three molecules of the monomer.

B. Simple Condensations

Examples already described in previous chapters are the *Claisen condensations* (Chap. XXIV) and ring closure with ethyl malonate (Exp. 258). Further examples are given in Exps. 284–297.

1. The Perkin Condensation.

Aromatic aldehydes when heated with a salt of a carboxylic acid in the presence of acetic anhydride yield unsaturated

acids, provided the acid contain two hydrogen atoms in the α-position, e.g.

$$C_6H_5CH\boxed{O + H_2}CH{\cdot}CO_2Na \rightarrow C_6H_5CH{:}CH{\cdot}CO_2H$$

$$C_6H_5CH{:}CH{\cdot}CH\boxed{O + H_2}CH{\cdot}CO_2Na \rightarrow C_6H_5CH{:}CH{\cdot}CH{:}CH{\cdot}CO_2H.$$

Experiment 284.—Cinnamic acid, $C_6H_5CH{:}CH{\cdot}CO_2H$, **from benzaldehyde and sodium acetate.**

2 parts by weight of benzaldehyde, 3 of acetic anhydride, and 1 of *anhydrous* finely powdered sodium acetate (Exp. 13) are heated in a flask provided with a long and wide air condenser in an oil or metal bath at 180° for 8 hours. The product is poured while hot into excess of water, and the residual benzaldehyde removed by distilling with steam. The amount of water being large the cinnamic acid dissolves, with the exception of a small quantity of an oily impurity. If the solution is coloured, animal charcoal is added and the liquid boiled for some time, then filtered and allowed to cool. The cinnamic acid separates as lustrous plates, m.p. 133°. Yield, 70 per cent of theory.

The sodium salts of certain dibasic acids of the type of succinic acid also react with aromatic aldehydes in the presence of acetic anhydride. With sodium succinate and benzaldehyde a lactonic acid, phenylparaconic acid, is obtained, together with a certain amount of the $\beta\gamma$ unsaturated acid phenylisocrotonic acid, $C_6H_5{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CO_2Na$. The reaction probably proceeds in the following stages:

1. $C_6H_5{\cdot}CH{:}O + CH_2(CO_2Na){\cdot}CH_2{\cdot}CO_2Na \rightarrow C_6H_5{\cdot}CH(OH){\cdot}CH(CO_2Na){\cdot}CH_2{\cdot}CO_2Na.$

The acetic anhydride liberates the acid salt from the normal salt, and then water is eliminated from the acid salt.

2. $C_6H_5{\cdot}CH(OH){\cdot}CH(CO_2Na){\cdot}CH_2{\cdot}CO{\cdot}OH \rightarrow H_2O + C_6H_5{\cdot}\underset{\displaystyle O\text{———————}}{\underset{|}{CH}}{\cdot}CH(CO_2Na){\cdot}\underset{\displaystyle CO}{\underset{|}{CH_2}}.$

Sodium phenylparaconate

Experiment 285.—Phenylparaconic acid from benzaldehyde and sodium succinate.

Equimolecular quantities of anhydrous sodium succinate, pure benzaldehyde, and acetic anhydride are heated at 100–

110° for 10 hours. When cold the mixture is extracted twice with ether, and the ethereal solution shaken with sodium carbonate solution so long as acid is extracted. The alkaline solution is warmed gently to remove ether and then acidified with hydrochloric acid, when the phenylparaconic acid is precipitated together with a small amount of phenylisocrotonic acid, $C_6H_5{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CO_2H$. When dry the mixture is extracted with warm carbon disulphide, in which the unsaturated acid is readily soluble. The insoluble paraconic acid crystallizes from hot water in glistening needles, m.p. 99°. When the dry acid is heated at 100° it loses in weight to the extent of 2 per cent, and then melts at 109°. A further amount of the acid is obtained by acidifying the aqueous solution which has been extracted with ether.

2. The Knoevenagl Condensation.

Numerous condensations of a type analogous to the Perkin synthesis (Exps. 284 and 285) take place when the esters of malonic, acetoacetic or cyanoacetic acids are condensed with aldehydes or ketones—even cyclic ketones—through the agency of an amine catalyst. Knoevenagl has carried out numerous condensations of this type using diethylamine or piperidine as condensing agents. Certain primary bases or even ammonia may also be used.

It has also been shown that these bases can be used for bringing about condensations between free malonic acid and aldehydes or ketones. The nature of the product depends upon the conditions; in the cold, the product is an unsaturated dibasic acid, but at the boiling point of the solvent, generally a tertiary base, the corresponding monobasic acid is obtained.

$$CH_2(CO_2H)_2 + OCH{-}X \rightarrow X{-}CH{=}C(CO_2H)_2 \rightarrow X{-}CH{=}CH{\cdot}CO_2H.$$

Experiment 286.—Condensation of anisaldehyde and malonic acid to *p*-methoxycinnamic acid,* $CH_3O{\cdot}C_6H_4CH{:}CH{\cdot}COOH$.

10 g. of malonic acid are dissolved in 10 g. pyridine (or α-picoline), 13 g. of anisaldehyde and 5 drops of piperidine added, and the mixture heated under reflux on a water bath for 4 hours. The mixture is then poured into excess of dilute hydrochloric acid, the precipitated product filtered off and recrystallized from alcohol. It melts at 170° to a cloudy liquid, which does not finally clarify until a temperature of 185° is reached. Yield, 90 per cent.

* *Ingold* and *Shoppee*, J. C. S. 1929, 449.

Experiment 287.—Condensation of cinnamaldehyde and malonic acid to (*a*) **cinnamylidene-malonic acid,** $C_6H_5CH{:}CH\cdot CH{:}C(COOH)_2$ **and** (*b*) **cinnamylidene-acetic acid,** $C_6H_5CH{:}CH\cdot CH{:}CH(COOH)$.*

25 g. of cinnamaldehyde, 20 g. malonic acid, and 25 g. of pyridine (or α-picoline) are mixed in a small flask and 5 drops of piperidine added. The flask is corked and kept at ordinary temperature for at least 3 days, after which the contents are poured into excess of dilute hydrochloric acid. The precipitate is filtered off, washed with water, and crystallized from alcohol. The product in this case is cinnamylidene-malonic acid and consists of bright-yellow needles, m.p. 206°.

If the mixture as given above is boiled as in Exp. 286 for 4 hours, the product is cinnamylidene-acetic acid, which consists of colourless needles, m.p. 166°. Yield, 90 per cent.

These acids may be reduced, as in Exp. 263, at 30° to 1:4-dihydrocinnamylidene-malonic acid, $C_6H_5CH\cdot CH{:}CH\cdot CH(COOH)_2$, m.p. 112°, and dihydrocinnamylidene-acetic acid, $C_6H_5\cdot CH_2\cdot CH{:}CHCH_2\cdot COOH$, m.p. 31°, respectively. By heating in a basic solvent to temperatures above 200° they lose carbon dioxide and yield the corresponding diene hydrocarbon, 1-phenyl $\Delta^{1:3}$ butadiene, $C_6H_5\cdot CH{:}CH\cdot CH{:}CH_2$.

Experiment 288.—1-Phenyl-$\Delta^{1:3}$-butadiene from cinnamylidene malonic acid.†

50 g. of cinnamylidene-malonic acid and 30 g. of quinoline are placed in a small distilling flask and the mixture rapidly distilled using an air condenser. The distillate is taken up in ether, washed with dilute hydrochloric acid to remove quinoline and with sodium hydroxide solution to remove acid, and dried by solid potassium hydroxide. The ether is distilled off and the hydrocarbon distilled under reduced pressure. B.p. 95° (20 mm. pressure). Yield, 25 per cent. Fractions of higher boiling-point consist of polymerization products, e.g. bis-phenylbutadiene.

3. **The Diels-Alder Condensation.**‡

Dienes containing conjugate linkages can react with ethylene or acetylene derivatives whose unsaturated linkages have become activated by the presence of such groups as

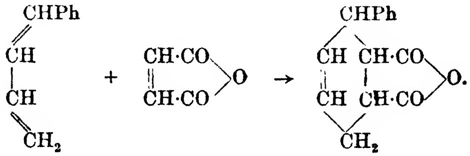
* Compare *Rüber*, B. 1904, 2274.

† *Liebermann* and *Rüber*, B. 1902, 2696.

‡ *Diels* and *Alder*, B. 1929, 2085.

·CO·, ·CN, attached to either of the two carbon atoms united by the unsaturated linkage.

The process, which strictly considered is an addition reaction, consists in the conversion of the double bond in such a compound into a single bond and the direct attachment of the two carbon atoms to the 1 and 4 carbon atoms of the diene, and the conversion of the single linkage between carbon atoms 2 and 3 into a double linkage. The result is the formation of a new six-membered carbon ring with one olefine linkage. Thus 1-phenyl-$\Delta^{1:3}$-butadiene (Exp. 288) reacts with maleic anhydride, yielding a reduced phthalic anhydride derivative.



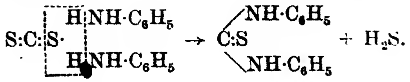
Experiment 289.—3-Phenyl-Δ^4-tetrahydrophthalic anhydride from 1-phenyl-butadiene and maleic anhydride.

10 g. phenylbutadiene and 7·5 g. maleic anhydride are heated on a boiling-water bath until reaction commences. The mixture is then removed from the water bath and allowed to stand until the reaction moderates. A small volume of benzene is then added, and the mixture again heated on the bath in order to complete the reaction. On standing, the product solidifies to a crystalline mass which, after crystallization from high boiling light petroleum, forms colourless needles, m.p. 120°. Yield theoretical.

The corresponding acid may be obtained by dissolving the anhydride in dilute alkali and precipitating with dilute acid.

4. **The Thiocarbanilide Condensation.**

Potassium hydroxide facilitates the condensation of substances which combine with the elimination of one or more molecules of an acidic compound; thus primary amines condense readily with carbon disulphide in the presence of this reagent, yielding substituted thiocarbamides,* e.g.



* *Hofmann*, A. 1849, **70**, 144.

Experiment 290.—Thiocarbanilide, $CS(NH\cdot C_6H_5)_2$, **from aniline and carbon disulphide.**

40 g. of aniline and 50 g. of carbon disulphide (excess) are added to 60 ml. of alcohol and 10 g. of powdered potassium hydroxide in a flask attached to a very long reflux condenser (or better, a double surface condenser). The mixture is heated on a boiling-water bath for 3–4 hours. The excess of carbon disulphide and alcohol is then distilled off, the residue washed with water, then with dilute hydrochloric acid in order to remove any unchanged aniline, and again with water. The substance is filtered and dried in a steam oven. Yield, 35 g., i.e. 70 per cent of theory.

A portion of the crude product is recrystallized from alcohol, and is deposited as large colourless plates, m.p. 151°, which are sparingly soluble in water but readily soluble in hot alcohol.

When boiled with mineral acids the substituted thioureas decompose, yielding isothiocyanates (thiocarbimides or mustard oils).

$$CS\left\langle\begin{array}{l}NH\cdot C_6H_5\\ \\ NH\cdot C_6H_5\end{array}\right. + HCl \rightarrow C_6H_5\cdot N{:}C{:}S + C_6H_5NH_2,\ HCl.$$

At the same time a portion of the unchanged thiourea condenses with the aniline set free in the above reaction, yielding a guanidine derivative:

$$(C_6H_5\cdot NH)_2C{:}S + H_2N\cdot C_6H_5 \rightarrow C\left\langle\begin{array}{l}NH\cdot C_6H_5\\ {:}N\cdot C_6H_5\\ NH\cdot C_6H_5\end{array}\right. + H_2S.$$

Experiment 291.—Phenyl isothiocyanate (phenyl mustard oil), $C_6H_5\cdot N{:}C{:}S$, **from thiocarbanilide.***

(*To be conducted in a fume chamber.*)

25 g. of the crude product obtained in the last experiment are distilled with 100 g. of concentrated hydrochloric acid from a large flask attached to a condenser. The mixture is heated on a sand bath until only about 20 ml. of liquid remain in the flask. The distillate is diluted with water, and the oil, which can be separated by means of a tap funnel, dried over calcium chloride, and redistilled, using an air condenser.

* *Hofmann*, J. 1858, 349.

The product is a colourless liquid with a pungent odour resembling that of mustard oil. B.p. 222°; $D_{4°}^{15°}$, 1·135.

The residue in the flask contains the by-product triphenylguanidine (cf. Exp. 294).

Isolation of the by-product triphenylguanidine,

$$C\begin{cases} NH{\cdot}C_6H_5 \\ {:}N{\cdot}C_6H_5 \\ NH{\cdot}C_6H_5 \end{cases}.$$

The residue in the flask after distillation of the phenyl mustard oil is diluted with 75 ml. of water, and allowed to stand for several hours. The crystals of triphenylguanidine hydrochloride are filtered off, and the free base isolated by warming the hydrochloride with a little dilute alkali. It is filtered off and recrystallized from a little alcohol.

Characteristic Reactions of the Mustard Oils.

(i) The mustard oils form additive compounds (substituted thioureas) with ammonia,* hydroxylamine, and amino-compounds, e.g.

$$C_6H_5N{:}C{:}S + NH_3 \rightarrow C_6H_5NH{\cdot}CS{\cdot}NH_2.$$

Experiment 292.—Heat a small quantity of phenyl isothiocyanate with a little alcohol and concentrated ammonia solution for a few minutes. On cooling, crystals of phenyl thiocarbamide separate. M.p. 154°.

Treated similarly with aniline, diphenyl-thiocarbamide is formed:

$$C_6H_5N{:}C{:}S + H_2N{\cdot}C_6H_5 \rightarrow (C_6H_5NH)_2{:}C{:}S.$$

(ii) When boiled with alcohols the mustard oils yield esters of thiocarbanilic acid,† e.g.

$$C_6H_5N{:}C{:}S + HO{\cdot}Et \rightarrow C_6H_5NH{\cdot}CS{\cdot}OEt.$$

Experiment 293.—5 g. of phenyl mustard oil are boiled with 15 ml. of absolute alcohol in a reflux apparatus on a water bath for three hours. The product is poured into cold water, and the solid which separates is recrystallized from alcohol. M.p. 67°.

(iii) When heated with yellow mercuric oxide the isothiocyanates are converted into the corresponding oxygen compounds.

$$C_6H_5N{:}C{:}S + HgO \rightarrow C_6H_5N{:}C{:}O + HgS.$$

* *Hofmann*, J. 1858, 349. † *Ibid.*, B. 1870, 3, 772.

The mercuric oxide blackens owing to formation of the sulphide. The phenyl isocyanate is detected by its characteristic irritating odour.

Triphenylguanidine is obtained in larger amount by the condensation of thiocarbanilide with aniline through the agency of *lead oxide* or *mercuric oxide* (cf. equation above).

Experiment 294.—Triphenylguanidine.*

10 g. of thiocarbanilide (Exp. 290) and 5 g. of aniline dissolved in 50 ml. of alcohol are heated in a beaker on a water bath. 15 g. of litharge are gradually added, the mixture being frequently stirred. The product is filtered while hot, and the residue is washed several times with hot alcohol. On cooling, triphenylguanidine separates as crystals. These are filtered off and the mother liquor poured into water, whereby the remaining substance is precipitated. The yield is almost quantitative, and the product crystallizes from alcohol in colourless needles, m.p. 143°.

5. **The Skraup Quinoline Synthesis.**

This consists in the condensation of an amino-compound with glycerol and an oxidizing agent in the presence of concentrated sulphuric acid, e.g.

$$\begin{matrix} CH{:}CH{\cdot}CH \\ \dot{C}H{:}CH{\cdot}\ddot{C}{\cdot}NH_2 \end{matrix} + \begin{matrix} OH{\cdot}CH_2{\cdot}CH{\cdot}OH \\ \dot{C}H_2{\cdot}OH \end{matrix} + O \rightarrow \begin{matrix} CH{:}CH{\cdot}C{\cdot}CH{:}CH \\ \dot{C}H{:}CH{\cdot}\ddot{C}{\cdot}N{=}\dot{C}H \end{matrix} + 4H_2O.$$

Nitrobenzene is generally used as oxidizing agent, but arsenic acid gives better results.

Experiment 295.—Quinoline, C_9H_7N, from aniline and glycerol.

36 g. of aniline, 24 g. of nitrobenzene, and 100 g. of glycerol are mixed in a large flask, and 100 g. of concentrated sulphuric acid added gradually, with shaking. The flask is then fitted to a *long and wide reflux condenser*, and heated on a sand bath until the reaction commences, as shown by the sudden evolution of bubbles of white vapour throughout the liquid. The source of heat is removed immediately, and the vigorous reaction allowed to continue without the further aid of external heat. When the reaction has moderated, the contents of the flask are further heated for two to three hours. The product is diluted with water and steam-distilled in order

* *Ibid.*, B. 1869, 2, 458.

to remove unchanged nitrobenzene. The residue in the flask is then made alkaline by the gradual addition of strong sodium hydroxide solution, and again distilled with steam. The distillate contains both quinoline and aniline. To remove the aniline, the distillate is treated with dilute sulphuric acid until the oil is completely dissolved and an excess of acid is present. The solution is cooled, and then treated gradually with a solution of sodium nitrite, until a drop of the liquid gives a blue coloration with potassium iodide-starch paper. By this means the aniline is diazotized, while the tertiary amine, quinoline, is unchanged. The product is boiled for some time on a water bath to convert the diazo-compound into phenol, again made alkaline, and distilled with steam. The quinoline now passes over in a pure condition, and is taken up with ether; the ethereal solution is dried with solid potassium hydroxide, the ether removed, and the residue distilled, when the base is obtained as a colourless liquid with a characteristic odour. B.p. 237°; $D^{0°}_{4°}$, 1·108. It has the properties of a tertiary base (cf. Chap. XVIII, E). Yield, 35 g., i.e. 70 per cent of theory.

For alizarin blue, see Chap. XXXI, B.

6. The Ullmann Condensation.

This consists in using finely divided copper—copper bronze—to eliminate the halogen from two molecules of an aryl halide and in this manner unite the two aromatic nuclei.

The simplest example is the formation of diphenyl from iodobenzene, but the method has found very general application in the synthesis of diphenyl, dinaphthyl, and more complex derivatives.

Experiment 296.—Diphenyl from phenyl iodide.*

Equal weights (10 g. each) of iodobenzene and copper bronze are heated together in a sealed tube at 230° for 3 hours. The solid product is extracted with ether and, after removal of the ether, the diphenyl is purified by sublimation. Yield, 4–5 g.; m.p. 71°.

Where the original compound is not too volatile the mixture can be heated in an open tube at 200–220°, being stirred with a thermometer.

7. The Crum-Brown Synthesis.

Condensation in the electrolytic cell.—In the electrolysis of salts of organic acids the complex residue which separates at the anode is generally incapable of independent existence,

* A. 1904, **332**, 40.

and consequently undergoes decomposition or condensation (cf. Exp. 15). The electrolysis of the alkali salts of the mono-ethyl esters of dicarboxylic acids affords a means for the preparation of higher acids of the same series, e.g. potassium ethyl succinate, $CO_2Et{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2K$, on electrolysis yields the monovalent residue, $CO_2Et{\cdot}CH_2{\cdot}CH_2{\cdot}CO{\cdot}O{\cdot}$, which when released at the anode decomposes according to the equation,

$$2CO_2Et{\cdot}CH_2{\cdot}CH_2{\cdot}CO{\cdot}O{\cdot} \rightarrow \begin{matrix} CH_2{\cdot}CH_2{\cdot}CO_2Et \\ \dot{C}H_2{\cdot}CH_2{\cdot}CO_2Et \end{matrix} + 2CO_2.$$

Experiment 297.—Ethyl adipate, $CO_2Et{\cdot}(CH_2)_4{\cdot}CO_2Et$, from potassium ethyl succinate.*

50 ml. of a concentrated aqueous solution of potassium ethyl succinate (1·5 part of the salt to 1 part of water; cf. Exp. 95) are placed in a narrow beaker. The latter should not be more than half full, and should be cooled by standing in ice water. A platinum spiral is introduced as anode, the cathode being a platinum sheet, and the current used should be 50–100 amperes per square decimeter of anode surface. The arrangement of the apparatus should be as shown in fig. 75.

The electrolyte froths considerably during the experiment, gas is evolved, and an oily layer of adipic ester appears on the surface of the aqueous solution. At least fifteen ampere-hours should be employed. The oil is separated from the solution, washed with water, dried with calcium chloride, and distilled under diminished pressure. The lower boiling fraction contains ethyl acrylate; the higher fraction is collected separately and redistilled under atmospheric pressure, when it passes over at 245°. Yield, 30–35 per cent of theory.

C. Long-Chain Polymerization and Polycondensation

1. The polymerization of ethylenic derivatives, particularly styrene, takes place slowly in the liquid phase at ordinary temperature:

$$n \begin{matrix} CH{=}CH_2 \\ | \\ C_6H_5 \end{matrix} \rightarrow \begin{matrix} —CH—CH_2—CH—CH_2—CH—CH_2— — — \\ \ \ | \qquad\qquad\quad | \qquad\qquad\quad | \qquad\qquad\qquad\qquad \\ C_6H_5 \qquad\quad C_6H_5 \qquad\quad C_6H_5 \qquad\qquad\qquad \end{matrix}$$

* *Crum Brown* and *Walker*, T. R. S. E. 1891, **36**, 211, or A. 1891, **261**, 117.

but is promoted by rise of temperature. It is powerfully catalysed by light and by atmospheric oxygen, by organic peroxides and certain metallic halides such as stannic chloride and antimony pentachloride. It is inhibited by certain antoxidants such as hydroquinone and also by hydrogen chloride gas. The reaction is reversible, for polystyrene on heating to 320° breaks down, though not completely, into monomeric styrene.

Experiment 298.—The polymerization of styrene.

Styrene, prepared from cinnamic acid or by distillation of commercial polystyrene, is purified by redistillation and the following tests applied:

(*a*) Portions are placed in small test tubes and the effect of bright light, heat (100°) and small additions of metallic sodium, benzoyl peroxide, hydroquinone and antimony pentachloride separately examined.

(*b*) Styrene is dissolved in alcohol and a little stannic chloride added. The solution becomes warm and an amorphous mass of polystyrene soon separates out.

Polystyrene is not a definite material having a constant set of properties. Various preparations can be separated by fractional extraction or precipitation into fractions of different properties and molecular weights. All fractions are soluble in benzene but the lower ones only in ether, and this difference can be used for their separation.

2. In polycondensation, e.g. the combination of dihydric alcohols with dibasic acids to form polyesters, the reactions take place as a step-wise process:

$$
\begin{array}{l}
---HO-CH_2-CH_2-OH + HO-CO-CH_2-CH_2-CO-OH \\
\qquad + HO-CH_2-CH_2-OH + HO-CO-CH_2-CH_2-CO-OH \\
\qquad + HO-CH_2-CH_2-OH --- \rightarrow \\
---O-CH_2-CH_2-O-CO-CH_2-CH_2-CO-O-CH_2-CH_2-O \\
\qquad\qquad -CO-CH_2-CH_2-CO-O---
\end{array}
$$

Ethylene glycol + succinic acid → ethylene succinate polyester

Experiment 299.—Ethylene succinate polyester.*

Approximately molecular proportions of succinic acid and ethylene glycol, with the latter in slight excess, are mixed in a flask arranged for distillation under diminished pressure (fig. 5) and heated in an oil or metal bath. At 160–175° rapid esterification takes place accompanied by the evolution of water. When no more water is being evolved the tempera-

* *Carothers* and *Dorough*, J. A. C. S. 1930, 52, 711.

ture is raised to 220–250° and the pressure reduced to less than 1 mm., under which conditions the excess of glycol distils over. The ester product remains in the distilling flask as a thick viscous liquid which is poured out into a mortar and solidifies on cooling to a hard, brittle, opaque white mass. It is dissolved in cold chloroform and precipitated as a granular powder by the addition of ether or benzene. A portion is recrystallized from hot ethyl acetate or a large volume of hot acetone. M.p. 102°.

An estimate of the molecular weight of the product may be obtained by Rast's method. This is of the order of 3000 and its formula may therefore be represented as

$$H—[O—(CH_2)_2—O—CO—(CH_2)_2—CO—]_{22}—O—(CH_2)_2—OH.$$

By heating this substance to 340–390° under a pressure of 3–4 mm. a volatile product is obtained which condenses to a crystalline solid of m.p. 129–130° which is a dimeric form of ethylene succinate.

A classical example of polycondensation is the formation of polypeptides by *Fischer's method* (S.B. Chap. LXVII), where the acyl group of one amino acid becomes attached to the amino-group of another molecule of the same acid or of another acid.

$NH_2·CH_2·CO·NH·CH_2·COOH$, Diglycine.
$CH_3·CH(NH_2)·CO·NH·CH_2·COOH$, Alanylglycine.

The process can be continued step-wise and in this way the product *l*-leucyl-triglycyl-*l*-leucyl-triglycyl-*l*-leucyl-octaglycyl-glycine has been formed. This contains 18 amino acid groups and has a molecular weight of 1213.

The natural substances starch and cellulose are polycondensation products with glucose residues as the links in the chain.

XXIX. GRIGNARD REAGENTS
(S.B. 139–143)

Practically all halogen derivatives, with the exception of acyl halides, react with metallic magnesium, forming additive compounds of the type R·Mg·X (R = alkyl, X = halogen), which are usually termed Grignard reagents.* These sub-

* *Grignard*, C. R. 1900, **130**, 1322; *Runge*, Organo-Magnesium-Verbindungen, Stüttgart, 1932.

stances are of enormous value as synthetical reagents, as by means of them the following groups of compounds can be synthesized: Paraffins, olefines, benzene homologues, primary, secondary and tertiary alcohols, aldehydes, ketones, acids, phenols, sulphinic acids, and organo-metallic compounds. The reagents are usually prepared in the presence of perfectly dry ether, but they may also be obtained in dimethylaniline solution, or in benzene solution containing a small amount of ether, or of a tertiary base, or even by heating the metal and alkyl iodide.

When ether is used as solvent a compound of the type $CH_3{\cdot}Mg{\cdot}I, (C_2H_5)_2O$, or $CH_3{\cdot}Mg{\cdot}I, 2(C_2H_5)_2O$, is formed. These compounds are comparatively stable, and react in the same manner as the simple compound, $CH_3{\cdot}Mg{\cdot}I$. When aryl halides are used it is often necessary to add a crystal of iodine or a drop or two of methyl iodide to start the reaction.

For use of a Grignard reagent in estimating hydroxyl, see Exp. 145.

A. Preparation of a Grignard Reagent

Experiment 300.—Phenyl magnesium bromide, $C_6H_5{\cdot}Mg{\cdot}Br$. For success in this preparation the reagents must be thoroughly dry. Magnesium in the form of clean ribbon is dried in an oven at 110–112° for several hours. The phenyl bromide is allowed to stand for some time over fused calcium chloride and then redistilled. The ether is purified and dehydrated as in Exp. 29.

2·4 g. of magnesium are placed in a dry flask of 250 ml. capacity together with about 50 ml. of ether and 15·7 g. of monobromobenzene. The flask is attached to a reflux condenser, the inner tube of which has been thoroughly dried, and is heated gently on a water bath. If the reaction does not commence soon, it is facilitated by the addition of a fragment of iodine, and the heating is continued until all (or nearly all) the magnesium has dissolved. Access of moisture into the flask is prevented by fitting a calcium chloride tube to the upper end of the condenser.

In the preparation of Grignard's reagents small amounts of hydrocarbons are usually formed; e.g. in the above reaction, diphenyl:

$$2C_6H_5Br + Mg = C_6H_5{\cdot}C_6H_5 + MgBr_2.$$

This secondary reaction is especially noticeable with alkyl halides of high molecular weight.

B. Preparation of a Benzene Homologue

Experiment 301.—*p*-Xylene from *p*-bromotoluene.*

$$C_6H_4\begin{cases} CH_3 \ (1) \\ Mg{\cdot}Br \ (4) \end{cases} \rightarrow C_6H_4\begin{cases} CH_3 \ (1) \\ CH_3 \ (4) \end{cases}$$

50 g. of *p*-bromotoluene, 7·4 g. of magnesium, and 150 ml. of anhydrous ether are heated as in Exp. 300. When practically all the magnesium is dissolved a solution of 37 g. of methyl sulphate in dry ether is added. After the vigorous reaction has ceased the product is poured on to ice, the ether distilled off, and the residue subjected to steam distillation. The oil which passes over is separated and fractionated. Yield, 30 g., i.e. 74 per cent of theory. It is a colourless oil, b.p. 137–139°.

A small amount of solid *p*-ditolyl is deposited in the condenser when all the *p*-xylene has been driven over by the steam.

C. Synthesis of Secondary Alcohols

Experiment 302.—Benzhydrol, $(C_6H_5)_2CH{\cdot}OH$, from benzaldehyde.

$$C_6H_5{\cdot}Mg{\cdot}Br + C_6H_5{\cdot}CHO \rightarrow (C_6H_5)_2CH{\cdot}O{\cdot}MgBr$$
$$(C_6H_5)_2CH{\cdot}O{\cdot}MgBr + HCl \rightarrow (C_6H_5)_2CH{\cdot}OH + Mg(Br)Cl.$$

A solution of 10·6 g. of freshly distilled benzaldehyde in 25 ml. of dry ether is placed in a dry flask fitted with a reflux condenser, and the Grignard reagent, prepared as in Exp. 300, gradually added. A vigorous reaction occurs, and a precipitate of the intermediate compound (cf. equation) separates. The reaction is completed by heating the mixture on a water bath for fifteen to thirty minutes; it is then cooled, and poured gradually into excess of dilute hydrochloric acid, with continual shaking and cooling, until all the precipitate has dissolved. The aqueous layer is separated and extracted with ether, the extract added to the original ethereal solution, and the whole shaken with a dilute solution of sodium bisul-

* *Werner* and *Zilkins*, B. 1903, **36**, 2116.

phite to remove any unchanged benzaldehyde; it is then dried over anhydrous potassium carbonate, and the ether distilled off. The oily residue solidifies on standing, and the crystals are dried on a porous plate and recrystallized from light petroleum, when the benzhydrol is obtained as colourless needles, m.p. 68°, b.p. 298° (with decomposition). Yield, 13 g., 70 per cent of theory.

D. Synthesis of Tertiary Alcohols

Experiment 303.—Triphenyl-carbinol, $(C_6H_5)_3C{\cdot}OH$, from methyl benzoate.*

$$C_6H_5C\begin{matrix}\diagup O \\ \diagdown OMe\end{matrix} \rightarrow (C_6H_5)_2C\begin{matrix}\diagup O{\cdot}MgBr \\ \diagdown OMe\end{matrix} \rightarrow (C_6H_5)_3C{\cdot}O{\cdot}MgBr \rightarrow (C_6H_5)_3C{\cdot}OH.$$

The Grignard reagent, prepared as in Exp. 300, is added to a solution of 7 g. of methyl benzoate in 10 ml. of dry ether. After the reaction has moderated, the mixture is heated on a water bath for an hour to render it complete. It is then treated with hydrochloric acid, as in Exp. 302. The ether is removed, and the residue steam-distilled in order to remove unchanged bromobenzene and a little diphenyl. The carbinol which is not volatile with steam is recrystallized from alcohol, and is deposited as colourless crystals, m.p. 159°, b.p. above 360°.

Tertiary alcohols can also be prepared by the action of Grignard compounds on ketones and on acid chlorides. The initial magnesium products yield the alcohols when treated with dilute mineral acids.

$$C_6H_5{\cdot}Mg{\cdot}Br + (C_6H_5)_2C{\cdot}O = (C_6H_5)_3C{\cdot}O{\cdot}MgBr$$
$$(C_6H_5)_3C{\cdot}O{\cdot}MgBr + HCl = (C_6H_5)_3C{\cdot}OH + MgBrCl.$$

The yield is practically quantitative.

The methods illustrated by Exps. 302 and 303 provide means for the synthesis of alcohols containing asymmetric carbon atoms.

E. Preparation of Olefine Hydrocarbons

In attempting to prepare certain secondary and tertiary alcohols by means of Grignard reagents, olefines are frequently obtained, especially when the ether is removed and

* *Ullmann* and *Münzhuber*, B. 1903, 36, 406.

the residue heated; thus, when phenyl magnesium bromide reacts with acetyl chloride the product is not diphenyl-methyl carbinol, $(C_6H_5)_2C\langle^{OH}_{CH_3}$, but diphenyl-ethylene, $(C_6H_5)_2C:CH_2$.* These olefines are undoubtedly formed by the elimination of basic magnesium halides, e.g. $Mg(OH)I$, from the original product.

Experiment 304.—Diphenyl-propene, $(C_6H_5)_2C:CH{\cdot}CH_3$, from benzophenone and magnesium ethyl iodide.†

$$(C_6H_5)_2C{:}O \rightarrow (C_6H_5)_2C\langle^{O\cdot MgBr}_{CH_2\cdot CH_3} \rightarrow (C_6H_5)_2C{:}CH{\cdot}CH_3.$$

18 g. of finely divided and dry benzophenone are added to the Grignard compound obtained by dissolving 5 g. of dry magnesium and 32 g. of ethyl iodide in 50 ml. of anhydrous ether. The reaction is vigorous and the flask may require cooling. The mixture is ultimately heated for five hours on the water bath. It is then treated with dilute acid, extracted with ether, and the residue left after removal of the ether distilled under reduced pressure. The hydrocarbon distils at 169–170° under 18 mm. pressure. It solidifies on cooling to crystals, m.p. 52°, and may be crystallized from alcohol or light petroleum.

F. Synthesis of Carboxylic Acids

Carboxylic acids can be synthesized by passing carbon dioxide into ethereal solutions of Grignard compounds and then decomposing with water.

$$R{\cdot}MgI \rightarrow R{\cdot}CO{\cdot}OMgI \rightarrow R{\cdot}CO{\cdot}OH.$$

The yields are not always good, and tertiary alcohols are sometimes formed.

Another method of synthesizing acids in the form of their esters is by the action of ethyl chloroformate, $Cl{\cdot}CO_2Et$, on the ethereal solution of the Grignard compound.‡

$$R{\cdot}Mg{\cdot}Cl + Cl{\cdot}CO_2Et \rightarrow R{\cdot}CO_2Et + MgCl_2.$$

* *Tissier* and *Grignard*, C. R. 1901, **132**, 1182.
† *Klages*, B. 1902, **35**, 2647.
‡ *Houben*, B. 1903, **36**, 3087.

If excess of the Grignard compound is used, appreciable amounts of tertiary alcohols are formed.

Experiment 305.—Triphenylacetic acid, $(C_6H_5)_3C{\cdot}CO_2H$, **from triphenylchloromethane.***

(*a*) Preparation of triphenylchloromethane from carbon tetrachloride and benzene. (Application of *Friedel* and *Craft's* reaction, Chap. XXI, B.)

$$CCl_4 + 3C_6H_6 \rightarrow Cl{\cdot}C(C_6H_5)_3 + 3HCl.$$

10 g. of dry carbon tetrachloride and 35 g. of pure dry benzene are placed in a flask fitted with a long reflux condenser, 12·5 g. of freshly prepared and powdered aluminium chloride (Chap. XXXVIII) are added in two or three portions. When the vigorous reaction has ceased, the mixture is heated for an hour on the water bath, then cooled and carefully poured on to ice, surrounded by a freezing mixture. The addition must be carried out very slowly and the mixture well stirred, benzene being added to dissolve the triphenylchloromethane as it separates. The benzene solution is removed, washed with dilute hydrochloric acid, then rapidly with a little water, dried over calcium chloride, and concentrated on the water bath. About 50 per cent of the chloro-compound crystallizes on cooling, and a further quantity is obtained by removing the benzene from the filtrate under diminished pressure and washing the residue with ether.

It forms colourless crystals, m.p. 108–112°. Yield, 70–85 per cent.

(*b*) Preparation of triphenylacetic acid.

A mixture of 10 g. of triphenylchloromethane, 0·05 g. of iodine, 50 ml. of dry ether, and 2 g. of magnesium ribbon is heated in a reflux apparatus to boiling, and a stream of dry carbon dioxide led into the boiling solution for some three hours, or until the red colour disappears and the liquid is filled with a lemon-yellow precipitate. The mixture is shaken from time to time, and ether is periodically added as it is removed by the carbon dioxide. When the reaction is complete, 60 ml. of water are added to the flask, the mixture well shaken, poured into a dish, and gradually treated with 40 ml. of concentrated hydrochloric acid. The whole is boiled for five minutes and well stirred. When cold, the crude acid

* *Schmidlin*, B. 1906, 39, 634.

is filtered off, washed, and then boiled in a dish with 200 ml. of 10 per cent sodium hydroxide solution and 100 ml. of water. After dilution with 300 ml. of water and allowing to cool, the mixture is filtered and the clear filtrate treated with 100 ml. of concentrated hydrochloric acid. To render the precipitated acid more granular the mixture is heated for some time, then cooled, filtered, and the precipitate washed and dried. Yield, 8·5 g., i.e. 83 per cent of theory.

It crystallizes from glacial acetic acid in long, glistening prisms, m.p. 264–265°.

G. Reformatsky's Reaction

In many cases it is not necessary to prepare the Grignard compound separately, but it suffices to introduce magnesium (or usually zinc) and the halogen derivative directly into the other reacting substance. (*Reformatsky's reaction.**)

Experiment 306.—Ethyl β-hydroxy-αβ-dimethylbutyrate from acetone, zinc, and ethyl α-bromopropionate.†

$$(CH_3)_2C{:}O + CH_3{\cdot}CHBr{\cdot}CO_2Et + Zn \rightarrow$$

$$(CH_3)_2C\begin{matrix}\diagup OZnBr \\ \diagdown CH(CH_3){\cdot}CO_2Et\end{matrix} \rightarrow \begin{matrix}CH_3\diagdown \\ CH_3\diagup\end{matrix}C(OH){\cdot}CH(CH_3){\cdot}CO_2Et.$$

To a mixture of 90 g. of pure dry acetone and 182 g. of ethyl α-bromopropionate ‡ contained in a large flask fitted with a wide reflux condenser, a small amount of dry and carefully cleaned zinc § is added. On warming gently on a water bath a reaction commences and usually proceeds very briskly, the flask sometimes requiring to be cooled. When the reaction subsides more zinc is added, and this is repeated until there is some zinc left undissolved (about 45 g. of the metal are required). After the mixture has been heated for 2–3 hours on a boiling-water bath, the syrupy product is poured off as far as possible from the residual zinc and treated with

* J. R. C. S. 1890, **22**, 49.

† *W. H. Perkin*, J. C. S. 1896, **69**. 1482.

‡ Prepared from propionic acid, $CH_3{\cdot}CH_2{\cdot}COOH$, by application of the reactions illustrated by Exps. 44, 45, and 90.

§ Zinc filings are washed successively with hot alkali, then dilute acid, water, alcohol and ether, and finally dried in an air oven.

water. The mixture sets to a thick white paste, owing to the formation of zinc bromide, which is then dissolved by addition of dilute sulphuric acid. The thick oily ester which separates is taken up with ether; the ethereal solution is washed three times with dilute sulphuric acid and finally with water, and dried over calcium chloride. The ether is removed and the residue distilled under reduced pressure (30 mm., fig. 9); a considerable portion distils over below 100° at this pressure, but about 50 per cent of the oil distils at 105° and is the pure ester.

XXX. DYES

A. The Azo Dyes

(S.B. Chap. LIX, B. Cf. Chap. XX, H)

B. The Triphenylmethane Dyes

(S.B. Chap. XXX)

The hydrocarbon, triphenylmethane, $H{\cdot}C(C_6H_5)_3$, is the mother substance of a series of important dyes which may be considered as anhydro-derivatives of the salts of amino- or hydroxy-derivatives of triphenyl-carbinol, $HO{\cdot}C(C_6H_5)_3$. The entrance of three amino- or hydroxy-groups converts compounds of this type into dyes. Two amino-groups suffice for the development of the dyeing power only when the amino-hydrogen atoms are replaced by alkyl radicals.

The following are the chief groups:

1. **The Derivatives of Diamino-triphenylmethane: the Malachite-green Series.**

An aromatic aldehyde is condensed with a tertiary amine in the presence of zinc chloride.

$$C_6H_5{\cdot}CH\boxed{O + \begin{matrix} H{\cdot} \\ H{\cdot} \end{matrix}}\begin{matrix} C_6H_4{\cdot}NMe_2 \\ C_6H_4{\cdot}NMe_2 \end{matrix} \rightarrow H_2O + C_6H_5{\cdot}CH(C_6H_4{\cdot}NMe_2)_2.$$

The leuco-base, which is a derivative of diamino-triphenylmethane, is then oxidized to the corresponding carbinol,

$C_6H_5{\cdot}C(OH)(C_6H_4{\cdot}NMe_2)_2$, the dye base, which reacts with acids forming salts, and these immediately give up water and form the dye itself.

Experiment 307.—Malachite green from benzaldehyde and dimethylaniline.*

The dye is isolated in the form of its double salt with zinc chloride.

$$3\left(C\begin{matrix} \diagup C_6H_5 \\ - C_6H_4{\cdot}N(CH_3)_2 \\ \diagdown C_6H_4{:}N(CH_3)_2Cl \end{matrix}\right), ZnCl_2, H_2O.$$

(*a*) **Preparation of the Leuco-base, Tetramethyldiaminotriphenylmethane.**

50 g. of dimethylaniline, 20 g. of benzaldehyde, and 20 g. of freshly fused zinc chloride are heated for four hours in a porcelain dish on a water bath, care being taken that the mixture is frequently stirred. The product is melted by heating with water, and transferred while hot into a ½ litre flask, and subjected to steam distillation in order to remove any unchanged dimethylaniline. The leuco-base remains in the flask, and adheres to the glass; when cold the liquid is removed, the solid residue washed with water, and then dissolved in hot alcohol. After filtering, the solution is allowed to stand overnight in a cool place, when the base separates as colourless needles, which are filtered off and dried on filter paper. By concentrating the mother-liquor a second crop of crystals may be obtained. Should the base separate in the form of an oil, the alcoholic solution is too concentrated; in such a case more alcohol is added, the whole is redissolved, and the crystallization repeated.

(*b*) **Oxidation of the Leuco-base.**

$$C_6H_5{\cdot}CH[C_6H_4{\cdot}N(CH_3)_2]_2 + O \rightarrow \underset{\text{Dye-base (carbinol)}}{C_6H_5{\cdot}C(OH)[C_6H_4{\cdot}N(CH_3)_2]_2}$$

$$C_6H_5{\cdot}C(OH)[C_6H_4{\cdot}N(CH_3)_2]_2 + HCl \rightarrow \underset{\text{Malachite-green hydrochloride}}{C_6H_5C\begin{matrix} \diagup C_6H_4{\cdot}N(CH_3)_2 \\ \diagdown C_6H_4{:}N(CH_3)_2Cl \end{matrix}} + H_2O.$$

10 parts by weight of the leuco-base are dissolved in dilute hydrochloric acid containing exactly 2·7 parts of the anhydrous acid. The solution is diluted with 800 parts of water

* *Otto Fischer*, A. 1877, **206**, 122.

in a large flask, and treated with a 30–40 per cent solution of acetic acid containing 4 parts of anhydrous acid. The mixture is well cooled by adding pieces of ice, and is then oxidized by adding gradually a thin paste containing 7·5 parts of pure lead dioxide,* the whole being well shaken during the addition. After standing for five minutes, the solution is treated with a solution of 10 parts of sodium sulphate crystals in 50 parts of water, and filtered off from the precipitate of lead sulphate, &c. The filtrate is then treated with a filtered solution of 8 parts of zinc chloride in the least possible amount of water. On addition of excess of a saturated solution of common salt, the zinc chloride double salt of the dye separates, is filtered with the aid of the pump, and purified by redissolving in water and again salting out. It is finally dried on porous plate, and consists of bright-green crystals. The solution dyes silk, wool, &c., bluish-green.

Substituted benzaldehydes react in much the same manner as benzaldehyde, and various tertiary amines can be used instead of dimethylaniline.

2. **Dyes derived from Triamino-triphenylmethane. The Rosaniline-group.**

As an example of this class, magenta (fuchsine)

$$C\begin{cases} C_6H_4(CH_3)\cdot NH_2(3:4) \\ C_6H_4\cdot NH_2 \\ C_6H_4{:}NH_2Cl \end{cases}$$

may be cited. The dye is prepared by oxidizing a mixture of equimolecular proportions of *o*-toluidine, *p*-toluidine, and aniline (the mixture of bases is described as "aniline oil for red") by means of arsenic acid or nitrobenzene. When the latter oxidizing agent is used, a solution of iron in hydrochloric acid is also added; this serves to start the process, the ferrous chloride being oxidized by the nitrobenzene to ferric chloride, which then effects the oxidation of the mixture of bases. The nitrobenzene does not appear to take any part in the formation of the dye beyond acting as an oxidizing agent.

The reactions are as follows:

(i) *p*-toluidine is converted into the corresponding aldehyde:

$$CH_3\cdot C_6H_4\cdot NH_2(1:4) \rightarrow CHO\cdot C_6H_4\cdot NH_2(1:4).$$

* For preparation, see Chap. XXXVIII.

(ii) The aldehyde condenses with one molecule of *o*-toluidine and one of aniline to form the leuco-base.

$$NH_2\cdot C_6H_4\cdot HC{:}O \quad \begin{array}{l} + \overset{1}{H}\cdot C_6H_3(\overset{3}{CH_3})\overset{4}{NH_2} \\ \quad H\cdot C_6H_4\cdot\overset{4}{NH_2} \end{array}$$

$$\rightarrow H\cdot C\begin{cases} C_6H_4\cdot NH_2(1{:}4) \\ C_6H_3(CH_3)NH_2(1{:}3{:}4) \\ C_6H_4\cdot NH_2(1{:}4) \end{cases} + H_2O.$$

(iii) The leuco-base is oxidized to the carbinol, the hydrochloride of which forms the dye by the elimination of water.

$$HO\cdot C\begin{cases} C_6H_4\cdot NH_2 \\ C_6H_4(CH_3)NH_2 \\ C_6H_4\cdot NH_2 + HCl \end{cases} \rightarrow C\begin{cases} C_6H_4\cdot NH_2(1{:}4) \\ C_6H_4(CH_3)NH_2(1{:}3{:}4) \\ C_6H_4{:}NH_2Cl \end{cases} + H_2O.$$

Experiment 308.—Magenta.

10 g. of aniline and 40 g. of commercial toluidine (a mixture of 64 per cent of *o*-toluidine with 36 per cent of *p*-toluidine) are treated with 33 g. of concentrated hydrochloric acid in a round flask of 250 ml. capacity, 28 g. of nitrobenzene are added, and the mixture is heated to 100° in an oil bath. When this temperature is attained a solution of 1·5 g. of iron powder, in just sufficient hydrochloric acid to dissolve it, is added gradually. The flask is then fitted with an air condenser, and the temperature raised gradually to 180°, at which point it is maintained until a sample of the melt, withdrawn by means of a glass rod, solidifies on cooling. This requires four to six hours. The product is distilled with steam to remove nitrobenzene, &c., after which it is treated with 250 ml. of boiling water, and concentrated hydrochloric acid added until an acid reaction is obtained. 12 g. of common salt are added, and the whole boiled for a few minutes. The aqueous solution which contains the hydrochlorides of aniline and toluidine is then poured off; the residue on cooling sets to a green brittle mass, which is broken up and extracted with 750 ml. of boiling water to which 6 ml. of concentrated hydrochloric acid have been added. The magenta dissolves, and is filtered off from any insoluble matter; after cooling to 60° it is again filtered. Salt is added, and after cooling and standing for some time, the magenta is filtered off and recrystallized from water containing a little hydrochloric acid.

The dye forms greenish glistening crystals which dissolve in water to a red solution. It dyes silk and wool bluish red.

3. The Derivatives of Trihydroxy-triphenylmethane. The Aurine-group. (S.B. Chap. XXX, 3.)

Aurine,

$$C\begin{array}{l} \diagup C_6H_4OH \\ - C_6H_4OH, \\ \diagdown C_6H_4{:}O \end{array}$$

is prepared by heating a mixture of phenol, oxalic acid, and sulphuric acid, the oxalic acid providing the "methane carbon atom".

Experiment 309.—Aurine.*

6 parts of phenol, 3 parts of concentrated sulphuric acid, and 4 parts of *anhydrous* oxalic acid (Exp. 86) are heated, at 120–130°, by means of an oil bath in a round flask fitted with an air condenser for twenty-four hours. The melt is extracted with water, and the residue dissolved in hot alcohol. Ammonia gas is passed into the solution, and the precipitate formed is boiled with hydrochloric acid. The product is filtered and recrystallized from a mixture of alcohol and acetic acid.

It consists of brilliant green needles with a metallic lustre, dissolves in alkalis with a red colour, and is thrown down again on the addition of acids.

4. The Phthaleïns or Eosin-group.† (S.B. Chap. XXX, 4.)

These may be regarded, on the one hand, as derivatives of triphenylmethane, and on the other as derivatives of phthalic acid. They are prepared by the action of phenols on phthalic anhydride (cf. Chap. XVII, B, iii).

Experiment 310.—Phenolphthaleïn from phenol and phthalic anhydride.

$$C_6H_4\begin{array}{l} \diagup CO \diagdown \\ \diagdown CO \diagup \end{array}\!\!O + \begin{array}{l} H\,C_6H_4OH \\ H\,C_6H_4OH \end{array} \rightarrow C_6H_4\begin{array}{l} \diagup CO \text{———} \diagdown \\ \diagdown C(C_6H_4OH)_2 \diagup \end{array}\!\!O.$$

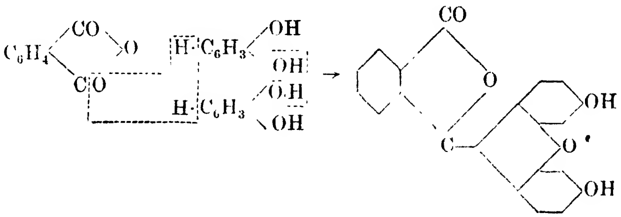
5 g. of phthalic anhydride (Exp. 100) and 10 g. of phenol are mixed with 4 g. of concentrated sulphuric acid in a boiling tube, and heated in an oil bath at 115–120° for eight hours. The mass which assumes a dark-red colour is poured while hot into excess of cold water, and boiled to remove excess of

* *Kolbe* and *Schmitt*, 1859.

† *Baeyer*, A. 1876, **183**, 1; 1880, **202**, 36.

phenol. The undissolved yellow powder is filtered off, washed with water, and extracted with dilute potassium hydroxide solution. The solution is filtered from any undissolved residue, and the filtrate acidified with acetic acid and a few drops of hydrochloric acid. The phthaleïn is reprecipitated, filtered off, and dried. For further purification it is boiled for an hour on a water bath with about six times its weight of absolute alcohol and a little animal charcoal (use a reflux apparatus), filtered, and the residue washed thoroughly with hot absolute alcohol. The solution is treated with about eight times its volume of cold water, and after stirring is filtered through a previously wetted filter paper in order to remove the resinous oil which separates. On heating the filtrate on a water bath for some time, the alcohol is evaporated and the phenol phthaleïn separates out as a white crystalline powder, m.p. 250–253°. It is only very sparingly soluble in water, more soluble in alcohol, readily in hot alcohol, and dissolves in alkalis, yielding a crimson solution.

Experiment 311.—Fluoresceïn from phthalic anhydride and resorcinol.*



An intimate mixture of 10 g. of phthalic anhydride (Exp. 100) and 15 g. of resorcinol is heated in a nickel crucible or porcelain dish in an oil bath to 180°. When this temperature is attained 5 g. of powdered fused zinc chloride are added gradually during ten minutes, the mixture being stirred with a glass rod. The temperature is then raised to 210°, and kept at this point until the mass becomes solid, for which one to two hours are required. After cooling, the solid mass is broken out with a chisel, powdered, and boiled for ten minutes with 200 ml. of water and 10 ml. of concentrated hydrochloric acid. The solution is filtered from the insoluble fluoresceïn, which

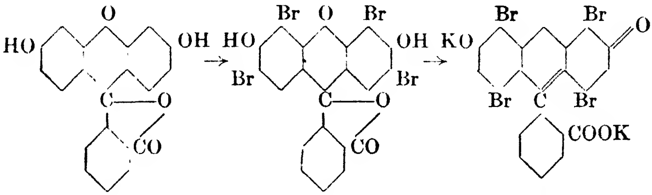
* *Baeyer*, A. 1876, **183**, 3.

is washed thoroughly with water and dried. Yield, almost quantitative.

It is a dark-red crystalline powder, which dissolves in alcohol with a yellow-red colour and in alkalis with a red colour and splendid green fluorescence.

When treated with bromine, fluoresceïn yields red crystals of tetrabromofluoresceïn, the potassium salt of which is the dye eosin.

Experiment 312.—Eosin from fluoresceïn.



Fluoresceïn Tetrabromofluoresceïn Eosin

15 g. of fluoresceïn are added to 60 g. of alcohol in a small flask, and 33 g. of bromine (11 ml.) are gradually added from a dropping funnel or burette. When half the bromine has been added, the dibromo-derivative which is formed has dissolved: on further addition of bromine the tetrabromo-derivative separates. After standing for two hours, the precipitate is filtered, washed with alcohol and then with water. It is converted into the potassium salt by mixing with a little hot water, carefully adding the exact amount of potassium hydroxide solution (two equivalents), and evaporating to dryness on the water bath.

It forms brownish-red crystals, and dyes wool or silk yellowish-red.

C. Anthraquinone Mordant Dyes—Alizarin

(S.B. Chap. LIX, K2)

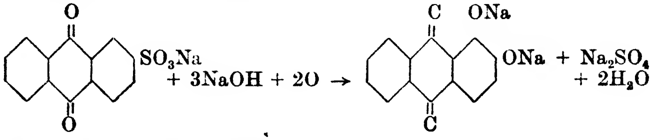
This important dye was originally obtained from madder root, in which it occurs in the form of a glucoside, ruberytheric acid, $C_{26}H_{28}O_{14}$ ($= HO\cdot C_{14}H_6O_2\cdot O\cdot C_{12}H_{14}O_3(OH)_7$), which yields alizarin and glucose when boiled with hydrochloric acid.*

$$HO\cdot C_{14}H_6O_2\cdot O\cdot C_{12}H_{14}O_3(OH)_7 + 2H_2O \rightarrow C_{14}H_6O_2(OH)_2 + 2C_6H_{12}O_6.$$

* *Liebermann* and *Bergami*, B. 1887, **20**, 2244.

Alizarin is a derivative of anthracene, for on distillation with zinc dust (cf. Exp. 271) it yields the latter compound.*

The dye is now prepared artificially by fusing anthraquinone-β-sulphonic acid with sodium hydroxide, potassium chlorate being added as oxidizing agent.



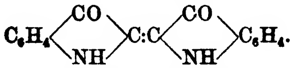
Experiment 313.—Alizarin.†

60 g. of sodium hydroxide are dissolved in 60 ml. of water, and 20 g. of sodium anthraquinonesulphonate (Exp. 129) added. 4 g. of potassium chlorate dissolved in 20 ml. of hot water are mixed with the mass, which is placed in an autoclave,‡ the lid of which is firmly screwed on, and heated for twenty hours at 170°. After cooling, the melt is extracted several times with boiling water, and the solution acidified with hydrochloric acid. The alizarin which separates is filtered with the aid of the pump, and dried on porous plate in a steam oven.

It is a yellow powder, which is only sparingly soluble in hot water, but readily soluble in alcohol and ether; when sublimed it forms long red needles, m.p. 290°. It dissolves in alkalis, yielding a purple-red colour, and from such solutions the calcium and barium salts may be obtained as blue precipitates. It dyes cotton mordanted with alumina (the fabric is immersed in aluminium acetate solution, and then heated) a scarlet-red colour; with ferric oxide, a dark-violet colour.

D. Vat Dyestuffs

Indigo Blue (Indigotin).



(S.B. Chap. LIX, K1.)

* *Graebe* and *Liebermann*, B. 1868, 1, 49.

† *Caro*, *Graebe*, and *Liebermann*, B. 1870, 3, 359.

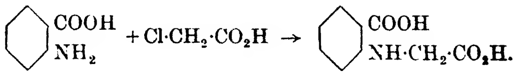
‡ An autoclave is a stout metal vessel, frequently enamelled inside, and in it substances can be heated under pressure. The vessel is provided with a metal lid, which can be screwed on and the whole made air-tight. A safety-valve and a manometer are attached to the autoclave, and by means of the latter the pressure inside the vessel is registered. In all cases the pressure must be kept well below that to which the special autoclave has been tested. The temperature is registered by means of a thermometer dipping into mercury contained in a depression of the lid.

This substance occurs in nature, especially in the indigo plant and in woad, as the glucoside indican, which yields indigo and glucose when hydrolysed with dilute acid.

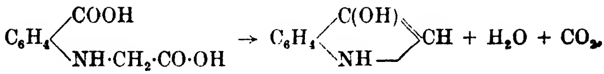
The dye is manufactured artificially on a large scale by an application of *Heumann's synthesis*, which consists of the following steps:

Naphthalene → Phthalic acid (Exp. 58) → Phthalic anhydride (Exp. 100) → Phthalimide (Exp. 108) → Anthranilic acid (Exp. 149).

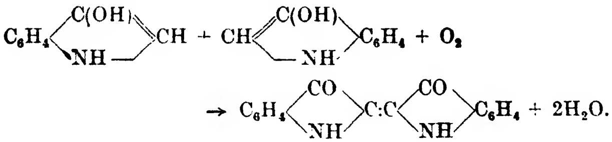
Anthranilic acid condenses with chloracetic acid, yielding phenyl-glycine-*o*-carboxylic acid.



The latter on fusion with potassium hydroxide yields indoxyl,



which can be oxidized to indigo blue.



Experiment 314.—Phenylglycine-*o*-carboxylic acid from anthranilic acid and chloracetic acid.*

13·6 g. of anthranilic acid (Exp. 149) and 9·4 of chloracetic acid are dissolved in 100 ml. of water containing 11·2 g. of potassium hydroxide in solution, and warmed in a reflux apparatus in a water bath at 60–80° for two hours. The product is neutralized with hydrochloric acid and allowed to stand, and the precipitated phenylglycine-*o*-carboxylic acid is filtered off and dried; a further yield is obtained by evaporating and cooling the filtrate. The acid is recrystallized from hot water, and is obtained as colourless crystals, m.p. (with decomposition) 200°. It is only sparingly soluble in water, and the alcoholic solution shows a blue fluorescence.

* *Heumann*, B. 1890, 23, 3432.

Experiment 315.—Indigo blue from phenylglycine-*o*-carboxylic acid.*

A mixture of 1 part of phenylglycine-*o*-carboxylic acid and 3 parts of potassium hydroxide is fused in a nickel crucible, the mass being well stirred by means of a thermometer.† At 180–200° the mass becomes yellow coloured, and subsequently reddish-yellow, and the heating is continued until the depth of the colour no longer increases. The cooled melt is added to about 200 parts of water, and a current of air led through the solution until a test portion, withdrawn for the purpose, no longer produces a bluish precipitate when air is drawn through. When the oxidation is completed the precipitate of indigo is filtered, washed successively with water, dilute hydrochloric acid, and alcohol, and finally dried.

Indigo forms a dark-blue powder with coppery lustre. It is insoluble in most solvents (including alkalis and acids), but dissolves to a blue solution in hot aniline, and to a red one in paraffin, from either of which it may be crystallized.

It is converted by reducing agents, e.g. grape sugar and sodium hydroxide, into the leuco-compound *indigo white*, $C_{16}H_{12}O_2N_2$, a white crystalline substance, soluble in alcohol, ether, and alkalis. The alkaline solution is oxidized rapidly by atmospheric oxygen, and indigo is deposited. In dyeing with indigo the fabric is impregnated with indigo white, which is then oxidized on the fabric.

XXXI. CONDENSED RING SYSTEMS. CYCLIZATION

A. Isocyclic Compounds

(S.B. Chaps. XXXI and XXXII)

The higher boiling fractions of coal tar contain a number of hydrocarbons of high molecular weight which possess formulæ with condensed ring systems. The most important of these are naphthalene, $C_{10}H_8$, anthracene, $C_{14}H_{10}$, and phenanthrene, $C_{14}H_{10}$; derivatives of these and other more complicated com-

* *Ibid.* 3434.

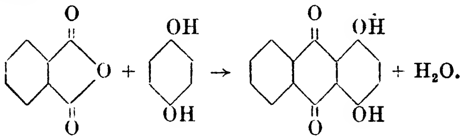
† Or, better, a short iron tube containing a thermometer.

pounds of similar type can be prepared synthetically from simpler open-chain or ring systems by methods of cyclization which are illustrated below.

1. **Anthracene Derivatives.**

Phthalic anhydride (and its substituted derivatives) condenses under the agency of anhydrous aluminium chloride with benzene (and its homologues and many substituted derivatives) to form keto-acids which readily undergo cyclization by the action of heat or dehydrating agents to form anthraquinones (Exp. 232). In some cases the condensation and cyclization may occur in one stage.

Experiment 316.—Quinizarin from phthalic anhydride and hydroquinone.



A mixture of 20 g. phthalic anhydride, 5 g. hydroquinone, 5 g. boric acid, and 50 ml. concentrated sulphuric acid is heated in a flask in an oil bath at 150–160° for 3 hours and then for 1 hour more at 190–200°. After partial cooling the mixture is carefully poured, with stirring, into 400 ml. of water and the precipitate filtered off. This is dissolved in 250 ml. of hot glacial acetic acid, filtered, and the filtrate diluted with an equal volume of hot water and allowed to cool. Crystals of quinizarin separate, which are filtered off, washed with water, and dried in a steam oven. Yield, 2 g.; m.p. 194°.

2. **Phenanthrene Derivatives.**

The Pschorr Synthesis.—By condensing an *ortho* nitrated benzaldehyde with sodium phenylacetate (the Perkin synthesis, p. 315) an α-phenyl-*o*-nitrocinnamic acid is obtained which, when reduced to the amino-compound, diazotized and treated with copper powder, yields a phenanthrene carboxylic acid.

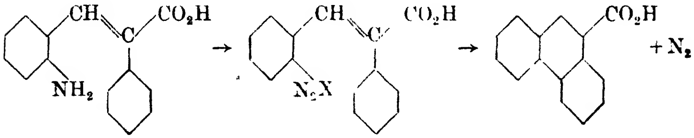
Experiment 317.—Phenanthrene from *o*-nitrobenzaldehyde.

(i) **α-Phenyl-*o*-nitrocinnamic acid.**—15 g. *o*-nitrobenzaldehyde, 16 g. sodium phenylacetate (dried at 130°), 2 g. fused zinc chloride and 180 g. acetic anhydride are heated together in an oil bath at 120° for 5 hours. The product is treated with 180 ml. of water, boiled for 5 minutes and then cooled. A

reddish-coloured oil separates which soon crystallizes, and the product is completely precipitated by addition of excess of water. It is filtered off, dried on the pump, and crystallized from 120 ml. of toluol. Yield, 14 g., 50 per cent; m.p. 195°.

(ii) **α-Phenyl-*o*-aminocinnamic acid.**—13·5 g. of the nitro-acid are dissolved in slight excess of dilute ammonia solution. 90 g. of ferrous sulphate crystals are dissolved in 900 ml. of water in a large flask heated on a water bath. The solution of the nitro-acid is added to the ferrous solution and then excess of strong ammonia solution, the heating continued for 15 minutes, and the mixture filtered on the pump. The filtrate, after cooling, is carefully neutralized with hydrochloric acid, and the precipitated acid filtered off, dried, and crystallized from toluol. Yield, 9 g., 75 per cent; m.p. 186°.

(iii) **Phenanthrenecarboxylic acid.**—



8 g. of the amino-acid are suspended in 160 ml. of water and dissolved by addition of sufficient dilute sulphuric acid. The solution is diazotized by careful addition of a solution of 3 g. sodium nitrite in 20 ml. of water. 10 g. of copper powder are added, and the mixture shaken until the diazonium salt is completely decomposed, as shown by the failure of a sample of the solution to couple with β-naphthylamine. The product is filtered and the precipitate extracted with dilute ammonia solution to separate the acid from the copper. The solution is acidified and the precipitated product separated and crystallized from acetic acid. Yield, 6–7 g. (90 per cent); m.p. 250°.

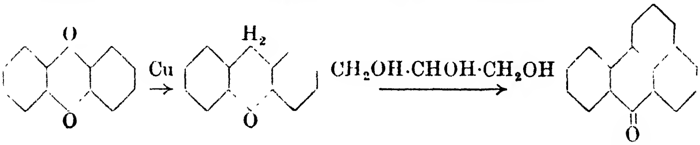
(iv) **Phenanthrene.**—The acid readily loses carbon dioxide on distillation. A portion is distilled in a small distilling flask or hard glass tube. The distillate is taken up with ether and the ethereal solution washed with dilute ammonia solution to extract unchanged acid. The ether is evaporated off and the residue crystallized from a little alcohol. M.p. 99°; picrate, m.p. 143°.

A modification of the above synthesis due to Windaus* consists in the use of oxindoles in the place of phenylacetic acid and of certain ketones in place of benzaldehydes.

3. Higher Condensed Systems.

Many polynuclear hydrocarbons are obtained from simpler compounds by pyrolysis, while synthetic methods are available for the preparation of derivatives. Thus the important dyestuff intermediate benzanthrone can be built up from anthraquinone by condensation of the latter with glycerol through the agency of concentrated sulphuric acid.

Experiment 318.—Benzanthrone from anthraquinone.



Benzanthrone

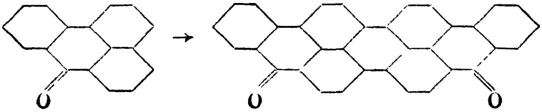
A three-necked litre flask is fitted with a mechanical stirrer, a thermometer and a tap-funnel, and is immersed up to the necks in an oil bath. 500 g. of concentrated sulphuric acid are placed in the flask, 35 g. of anthraquinone added, and the mixture stirred until the solid goes into solution. 20 ml. of water are then added, and 24 g. of precipitated copper introduced with constant stirring during a period of about an hour; meanwhile, the temperature of the mixture is raised to 40° and maintained by external heating until all the copper is dissolved.

A mixture of 48 g. of glycerol and 48 ml. of water is then added gradually during 30 minutes and the temperature gradually raised to 120°, at which it is maintained for 3 hours. The mixture is then partially cooled and carefully poured with stirring into 2 litres of hot water. After standing for some hours the dark-green precipitate is filtered off on a Buchner funnel, washed well with water, and then placed in a beaker with 500 ml. of 1 per cent sodium hydroxide solution, boiled for half an hour, again filtered and washed. Yield, 35 g.

This crude product is purified by boiling in portions with technical tetrachlorethane and animal charcoal, filtering while hot and adding to double the volume of hot alcohol. On cooling, yellow crystals of benzanthrone separate (m.p. 171°).

* B. 1924, 57, 1871, 1875.

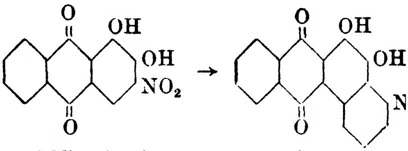
By fusion with potash at a temperature of 230–240°, benzanthrone undergoes further condensation to yield dibenzanthrone, which on oxidation with manganese dioxide and sulphuric acid gives a dihydroxy-derivative, the dimethyl ether of which is *Caledon jade green.*



Dibenzanthrone

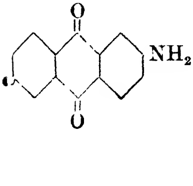
B. Heterocyclic Compounds

A number of condensations resulting in the production of heterocyclic ring systems have been described previously, e.g. the acetoacetic ester condensations (Exp. 247) and the Skraup quinoline synthesis (Exp. 295). The latter reaction has been applied to 3-nitro- (or amino-) alizarin to produce the dyestuff *alizarin blue.*

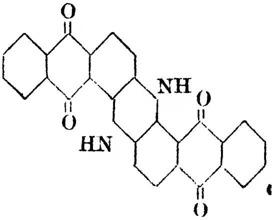


3-Nitroalizarin Alizarin blue

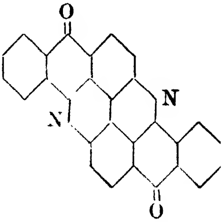
Fusion of 2-aminoanthraquinone with alkali results in the condensation of two molecules, with partial oxidation, to yield the condensed ring compounds *indanthrene* and *flavanthrene*, which are important vat dyestuffs.



2-Aminoanthraquinone



Indanthrene



Flavanthrene

Experiment 319.—Indanthrene from 2-aminoanthraquinone. 5 g. 2-aminoanthraquinone are mixed with 10 g. of powdered potassium hydroxide and 1 g. of potassium nitrate and heated in a hard glass tube to 250° in an oil or metal bath for an hour. The melt is extracted with water and the blue insoluble product filtered off, washed with dilute acid and water, dried and crystallized from nitrobenzene. It is obtained as blue needles with metallic lustre which decompose on heating at 470–500°. It yields a blue vat from which it dyes cotton a deep blue.

Experiment 320.—Flavanthrene from 2-aminoanthraquinone. 35 g. of antimony pentachloride (from ampoules) are added to 100 g. of dry nitrobenzene and the solution warmed to 60–80° in a flask without reflux condenser. 10 g. of 2-aminoanthraquinone are added gradually in small portions with shaking, and the mixture then heated to gentle boiling for an hour. On cooling, flavanthrene separates in pure form as yellow-brown needles which are filtered off and washed, first with nitrobenzene and then with ether.

It gives a purple-blue vat from which cotton is dyed a brilliant yellow.

XXXII. STEREOISOMERIC CARBON COMPOUNDS (S.B. Chaps. VI: X, B; X, D: XXVI, D: L)

When acids and other compounds containing one or more asymmetric carbon atoms occur naturally they are almost invariably optically active, and in the form of liquids or solutions rotate the plane of polarization of light to the right or left. When compounds of the same composition are synthesized in the laboratory from inactive materials they are invariably found to be optically inactive. This is due to the fact that in the synthetical formation the dextro and lævo modifications of the compound have been formed in equal amount, and the final product is thus a mixture of 50 per cent of *d* and 50 per cent of *l* acid, usually denoted by *d-l* (lactic) acid, or a definite compound of the *d* and *l* acids, when it is known as a racemic compound and denoted by *r*-acid. In either case it is possible to resolve such substances into their optically active components by Pasteur's methods (S.B. Chap. X, D).

A. Synthesis of Racemic Acids

Method I.—Racemic acids may often be prepared from aldehydes or unsymmetrical ketones by the addition of hydrogen cyanide (the cyanhydrin synthesis) and subsequent hydrolysis.

These cyanhydrins, and also the acids obtained on hydrolysis, contain an asymmetric carbon atom, e.g.

$$C_6H_5{\cdot}CH{:}O + HCN \rightarrow C_6H_5{\cdot}\underline{C}H(OH){\cdot}CN$$
$$C_6H_5{\cdot}\underline{C}H(OH){\cdot}CN + 2H_2O \rightarrow C_6H_5{\cdot}\underline{C}H(OH){\cdot}CO_2H + NH_3.$$

Experiment 321.—Mandelo-nitrile and mandelic acid.

(*a*) The nitrile of mandelic acid can be prepared by the direct addition of hydrogen cyanide to benzaldehyde,* but a more convenient method is to use the additive compound of the aldehyde and sodium bisulphite.† 15 g. of benzaldehyde (freshly distilled) are stirred in a stout beaker with about 50 ml. of a nearly saturated solution of the bisulphite. After some time the crystals are removed with the aid of the filter pump, washed with a little water, then with alcohol and ether. The crystals are then suspended in a small amount of water and a solution of 12 g. of potassium cyanide (98–99 per cent) in 25 ml. of water is added. If the mixture is stirred the crystals disappear, and the nitrile separates as an oil, which can be removed with the aid of a separating funnel and washed with water. Yield, 10–15 g.

(*b*) The nitrile may be hydrolysed by heating it on a water bath with four times its weight of concentrated hydrochloric acid, until the mandelic acid begins to crystallize. The mixture is then left overnight, and the crystals removed next morning. A further quantity of acid is obtained by extracting the filtrate with ether. It separates from benzene in colourless rhombic crystals, m.p. 118°. Yield, 80 per cent of theory.

Method II.—Racemic acids containing *two* asymmetric carbon atoms are often formed by the saturation of an acid containing an ethylene linkage by the addition of groups not already represented in the molecule, e.g.

$$C_6H_5{\cdot}CH{:}CH{\cdot}CO_2H + Br_2 \rightarrow C_6H_5{\cdot}\underline{C}HBr{\cdot}\underline{C}HBr{\cdot}CO_2H.$$

* B. 1881, 14, 239.
† D. R. P. 85,230.

Experiment 322.—Cinnamic acid dibromide (β-phenyl-αβ-dibromo-propionic acid), $C_6H_5 \cdot CHBr \cdot CHBr \cdot CO_2H$, from cinnamic acid.*

40 g. of finely divided cinnamic acid (Exp. 284) are spread out on a large clock-glass and placed in a desiccator over concentrated sulphuric acid. A dish containing slightly more than the theoretical amount of dry bromine is supported on a glass tripod above the cinnamic acid; the desiccator is closed and allowed to stand until all the bromine has evaporated from the dish and been absorbed by the acid; this occurs in about three days. The clock-glass is removed, the product exposed to the air for several hours, and then weighed in order to make sure that the theoretical amount of bromine has been absorbed. A portion of the product is then crystallized from alcohol, and is deposited as colourless needles, m.p. 197° (with decomposition). Yield, theoretical.

The two possible racemic compounds of formula $C_6H_5CHCl \cdot CHCl \cdot CO_2H$ can be prepared by the addition of chlorine to cinnamic acid under different conditions.

Experiment 323.—αβ-Dichloro-β-phenylpropionic acid from cinnamic acid.

10 g. of finely divided cinnamic acid are suspended in 50 ml. of carbon disulphide in a clear glass bottle fitted with inlet and exit tubes. Dry chlorine is bubbled through while the bottle is exposed to bright sunlight. Passage of the gas is continued at intervals throughout a day, after which the product is filtered off and washed with carbon disulphide. Yield, 14 g.; m.p. 163°.

Experiment 324.—*allo*-αβ-Dichloro-β-phenylpropionic acid from cinnamic acid.

10 g. of cinnamic acid are suspended in 50 ml. of carbon tetrachloride in a glass bottle which is kept in the dark and surrounded with ice. Chlorine is passed through the vessel until absorption ceases and the mixture is then allowed to stand. The passage of the gas is repeated intermittently until it is observed that practically all the cinnamic acid has gone into solution. The solution is then filtered into a porcelain dish and the solvent evaporated off in a vacuum desiccator attached to a pump. The product is a thick oily liquid which solidifies on long standing to colourless crystals. Yield, 14 g.; m.p. 76°.

* *Sudborough* and *Thompson*, J. C. S. 1903, **83**, 669.

The addition of bromine to fumaric acid (in ether) yields $\alpha\beta$-dibromo-succinic acid, m.p. above 200° (dec.), while careful addition to maleic acid in *pure dry* ether yields the isomeric $\alpha\beta$-*iso*-dibromo-succinic acid, m.p. 160°. The former is a *meso*-compound, while the latter is racemic and has been resolved into optically active components.*

Method III.—The *Hell-Volhard-Zelinsky reaction* (Exp. 44) when applied to propionic and more complex acids gives rise to racemic compounds containing an α-asymmetric carbon atom, e.g. $R{\cdot}CHBr{\cdot}CO_2H$.

Method IV.—The *Grignard reaction* (Exps. 302 and 303) may be applied to the preparation of racemic secondary and tertiary alcohols.

Experiment 325.—β-Phenyl-β-bromopropionic acid, $C_6H_5{\cdot}CHBr{\cdot}CH_2{\cdot}CO_2H$, **from cinnamic acid.**

10 g. finely divided cinnamic acid and 10 ml. of glacial acetic acid previously saturated with hydrogen bromide at room temperature are heated in a sealed tube for 2 hours at 100°; cold water is then added and the solid product washed, dried and recrystallized from dry carbon disulphide. Yield, 10 g., m.p. 137°. This acid is readily decomposed by warm water.

B. Resolution of Racemic Acids into the Optically Active Antipodes

Method I.—The biochemical method.

Experiment 326.—The action of Penicillium glaucum (ordinary green mould) on inactive mandelic acid.†

3 g. of mandelic acid in the form of its ammonium salt, and 1·25 g. of a mixture of various inorganic salts (potassium hydrogen phosphate, ammonium nitrate, and common salt), are dissolved in a litre of water. The solution is made distinctly acid with sulphuric or phosphoric acid, and is sterilized by boiling for half an hour in a flask closed with sterilized cotton-wool. When cold, a small amount of a pure culture of *Penicillium glaucum* is introduced by means of a sterilized platinum wire, the flask is immediately closed by reinserting the plug of sterilized cotton-wool, and allowed to stand in a warm room at constant temperature. When the increase of the fungus

* *McKenzie*, J. C. S. 1912, 1196.
† *Lewkowitseh*, B. 1883, 16, 1569.

is ended—which occurs in about six weeks—the solution is concentrated by evaporation, acidified, and the mandelic acid extracted with ether. The residue left after removal of the ether is crystallized from water, when *d*-mandelic acid separates as colourless crystals, m.p. 133°, and having $[\alpha]_D^{20°} = +156{\cdot}5$.

Method II.—Resolution by means of optically active bases.

The racemic acid is dissolved in a suitable solvent and treated with the equivalent amount of the active base, and the two salts formed are separated by fractional crystallization. In the majority of cases, it is better to use two equivalents of the acid and one of the base; under these circumstances the less soluble salt is formed and crystallizes out, and the mother liquor contains the other active component in the form of the free acid. The optically active acid can be separated from the salt by treatment with a mineral acid.

Experiment 327.—Resolution of cinnamic acid dibromide, $C_6H_5{\cdot}CHBr{\cdot}CHBr{\cdot}CO_2H$, into its optically active components.*

(a) *Preparation of* d-*acid by means of brucine.*

26·4 g. of cinnamic acid dibromide (Exp. 322) (two equivalents) and 20 g. of *l*-brucine, $C_{23}H_{26}N_2O_4 + 4H_2O$ (one equivalent) are dissolved in 560 ml. of *absolute* alcohol and allowed to stand in a large beaker. After about twenty-four hours, 20–25 g. of the brucine salt of the dextro acid (*d*-acid *l*-base) have crystallized out. The mother liquor is removed and the salt recrystallized *at least* three times from absolute alcohol. The product of the last crystallization is decomposed by treatment with dilute hydrochloric acid and the precipitated acid washed repeatedly with dilute hydrochloric acid until the filtrate no longer gives the reactions for brucine.

(b) *Preparation of the* l-*acid by means of cinchonidine.*

23 g. of cinnamic acid dibromide (1 mol) and 23 g. cinchonidine, $C_{20}H_{24}N_2O_2$ (1 mol), are dissolved in 500 ml. of benzene. The salt which separates is extracted at least five times by boiling with 100 ml. of benzene and filtering while hot. The residual salt is decomposed by treatment with dilute hydrochloric acid, and the product washed with acid until free from cinchonidine.

To obtain an acid of maximum rotation the above process should be repeated.

For determination of its rotatory power see Exp. 329.

* *Hirsch*, B. 1894, 27, 887.

Racemic bases can be resolved by similar methods using strong optically active acids, e.g. tartaric acid, *Reychler's acid* (camphor-10-sulphonic acid), and 3-bromo-camphor-8-sulphonic acid.

Racemic alcohols are resolved by union with phthalic anhydride to form acid esters (Exp. 94) which can be resolved by combination with optically active bases and the active alcohol obtained by hydrolysis.

Determination of Rotatory Power: The Polarimeter

A ray of ordinary light consists of ether vibrations in all directions in a plane at right angles to the axis of the ray. When it passes through a Nicol prism (a crystal of Iceland spar cut in a certain manner, cf. text-books of Physics), the emergent ether vibrations are all in the same direction and the light is said to be plane polarized. If this polarized light be examined through another Nicol prism, it is found that the light is transmitted through the second prism when the principal planes of the two prisms are parallel; when the planes are at right angles to one another no light passes through, while at intermediate positions a portion only of the light is transmitted, the amount depending on the angle which the two prisms make with one another. The position of maximum brightness is followed at an interval of 90° by a position of total darkness, and at an interval of 180° by a second position of maximum brightness, &c. The Nicol prism by which the light is polarized is called the polarizer, the one by which it is subsequently examined, the analyser.

If a tube containing a solution of cane sugar is placed between the two prisms when they are in the position of maximum darkness (i.e. at right angles to one another), the field of view becomes more or less bright. To attain the position of maximum darkness again, it is necessary to rotate the analyser through a certain angle. This indicates that the plane of polarization of the light falling on the analyser has been rotated by the solution, the degree of rotation being indicated by the angle through which the analyser must be turned in order to attain the position of maximum darkness again.

Substances, such as cane sugar (in the pure form or in

solution), which rotate the plane of polarization in this manner are said to be *optically active*; when the analyser must be rotated to the right in order to attain the position of darkness, the substance is *dextro-rotatory*; if to the left, *lævo-rotatory*. It is obvious that positions of darkness may be found on either side of the zero point, because in a complete revolution of 360° there are two positions each of maximum brightness and maximum darkness, but on one side the rotation will be greater than 90°. In determining the optical activity of a substance the sign of the rotation is taken as that in which it is less than 90°.

The angle of rotation produced in such a case as the above is found to depend on the following factors:

(i) The nature of the substance; if the substance is in solution this includes the concentration of the solution and the nature of the solvent.

(ii) The length of the layer of optically active substance through which the light passes.

(iii) The wave length of the light used.

(iv) The temperature.

These factors must be taken into account in determining the *specific rotatory power* of a substance, which is defined as the rotation produced by 1 g. of the active substance in 1 ml. by a layer 1 dcm. in length. This for sodium light (the D line) and temperature t is denoted by $[\alpha]^t_D$.

For a homogeneous optically active liquid (e.g. ethyl tartrate, Exp. 89), if α be the rotation produced for sodium light at a temperature t by a layer of the liquid l dcm. long, the density of the liquid being d, then

$$[\alpha]^t_D = \frac{\alpha}{ld}.$$

For a solution of the optically active substance in an inactive liquid the term d must be replaced by the number of grams of the substance in 1 ml. of solution. If c represent the concentration of the solution, i.e. the number of grams of substance in 100 ml. of solution,

$$[\alpha]^t_D = \frac{100\alpha}{lc}.$$

For purposes of comparison between different optically active substances the quantity termed *molecular rotation* is

used. This consists of the above quantity multiplied by the molecular weight of the substance and divided by 100 in order to avoid unwieldy numbers. It is denoted by $[M]^t_D$, and

$$[M]^t_D = \frac{[\alpha]^t_D \times M}{100}.$$

By comparison with the definition of specific rotatory power, this is seen to denote the angle of rotation produced by a layer of active substance 1 mm. thick containing 1 gram molecular weight in 1 ml.

The simple arrangement of two Nicol prisms described above is not sufficient for accurate work, for the analyser, when adjusted to intercept the light transmitted through the solution, can be rotated through a small angle in either direction without allowing any appreciable amount of light to pass.

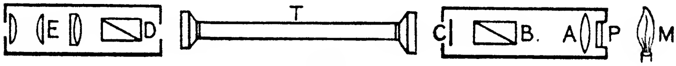


Fig. 92

Various forms of polarimeter have been invented to overcome this difficulty; the ones in general use are the Laurent and Lippich half-shadow polarimeters.

The arrangement of the optical parts of the Laurent polarimeter is shown diagrammatically in fig. 92. Monochromatic light from a sodium burner M passes through a thin plate or cell of potassium bichromate P, which absorbs blue or violet rays, and then through the collimating arrangement of lenses A; the parallel rays of light fall on the polarizing Nicol prism B, and then pass through the observation tube T, which contains the liquid under examination, to the analyser D, which is observed by the Galilean telescope E. At C a combination of glass and quartz semicircles termed a *half-shade* is introduced. The theory of this will be understood from the following considerations. Let ACB (fig. 93) represent a semicircular plate of quartz cut so that the optic axis is in the plane of the paper and parallel to AB. Plane-polarized light falling normally on the plate will be resolved into two sets of waves travelling along the same path but polarized in planes perpendicular to one another. Thus, if the plane of polarization at incidence is parallel to OP, the incident ray is polarized in the direction OP and the resolved vibrations will

be parallel to and can be represented by OX and OY respectively. The former is termed the ordinary, the latter the extraordinary ray. These traverse the quartz with different velocities, and if the thickness of the quartz is so chosen that the retardation of one ray with respect to the other is just half a wave length (a *half-wave* plate), the emerging rays can be represented by OY and OX′ (instead of OX). These will combine on emerging into a ray polarized in the direction OQ, where the angle AOQ = the angle AOP. The direction of polarization of the light passing through the glass portion of the half-shade is unchanged, so that the angle POQ represents the angle between the directions of polarization of the light passing through the two halves of the half-shade.

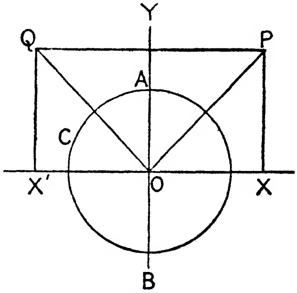


Fig. 93

If now, the polarizing prism being parallel to OP, the analyser is also placed parallel to OP, the two halves of the half-shade will appear unequally bright, for whereas in the glass half the whole of the light is transmitted, in the quartz half only the component of OQ along OP will pass through. If the analyser be rotated until it occupies a position parallel to OQ, the quartz half will be fully illuminated, while the glass half will only be partially so. Between these two positions there will necessarily exist a point at which the illumination is equally bright. By diminishing the angle YOP (i.e. the angle which the polarizer makes with the optic axis of the quartz), the transition can be made more abrupt, and thus more easily detected; but at the same time the illumination diminishes with the diminution of this angle. Consequently in practice the size of the angle must be chosen so as to give the best results. For clear colourless liquids the angle is made comparatively small, but in the case of coloured liquids it is necessary to increase it, and so obtain increased illumination at the cost of sensitiveness.

When a tube containing an optically active substance is introduced between the polarizer and analyser it will cause a rotation of the plane of polarization of the rays OP and OQ in the same sense and by equal amounts, and a measure

of this rotation is obtained by observing the rotation of the position of equal illumination of the two portions of the half-shade.

The complete polarimeter is shown in fig. 94. At S is placed a sodium lamp consisting of a Bunsen burner fed with common salt or borax or an electric sodium lamp. P is the polarizer, which can be rotated (thus altering the half-shadow angle)

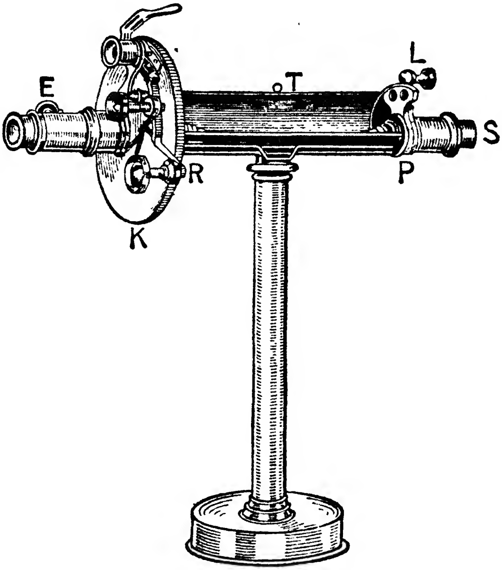


Fig. 94

by means of the lever L. The case T contains the observation tube. The analyser is at A, and can be rotated by means of a screw independently of the graduated circular disc K; this allows for the correction of the zero-point. The analyser and the telescope E can be made to rotate simultaneously by means of the rack-and-pinion arrangement R. Accurate readings are taken by means of verniers attached to the disc.

In working with the instrument reliance should not be placed on one reading only, but at least six observations should be made, which with a good instrument should not vary beyond 0·1°.

The Lippich polarimeter (fig. 95) differs from the above only in the method of producing the half-shadow. The half-shade plate is replaced by a small Nicol prism, which covers half the opening of the polarizer tube. This produces the same effect as the quartz plate. Moreover, in the more accurate type of instrument it enables the division of the field into three portions by the use of two small Nicols in this position. The instrument also possesses the advantage that it can be used with light of any wave length.

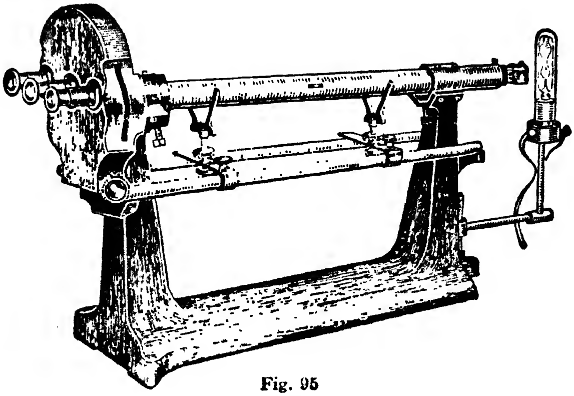


Fig. 95

Experiment 328.—Determination of the rotatory power of ethyl tartrate (Exp. 89).

A 200 mm. observation tube is filled with ethyl tartrate and allowed to stand for some time in order that any suspended particles present may settle. Meanwhile the zero of the polarimeter is determined, an observation tube filled with water being placed in position. The half-shade angle is fixed by means of the lever L, so that the transition is as sharp as possible consistent with a sufficiency of illumination, and the position of equal illumination of the two semicircles determined as accurately as possible, several separate readings being taken. The tube containing ethyl tartrate is then placed in position, and the position of equal illumination again determined, the mean of several readings being taken. Hence the specific rotatory power and molecular rotation of the substance is calculated from the formulæ given above.

For ethyl tartrate $[\alpha]_D^{20^\circ} = +7 \cdot 66$.

Experiment 329.—Determination of the specific rotatory power of the resolved cinnamic acid dibromide.

The acids separated from the brucine and cinchonidine salts in Exp. 327 are dissolved in absolute alcohol. For this purpose 2 g. of the dry substance is dissolved in the alcohol, and the solution made up to 20 ml. The solution is placed in a 200 mm. tube, and the rotation determined as in the above experiment.

Specific rotatory power of cinnamic acid dibromide = $\pm 64°$.

Temperature has a considerable effect on the specific rotation of optically active substances, the molecular rotation gradually increasing with rise of temperature.

Experiment 330.—Determine the specific rotatory power of ethyl tartrate at several different temperatures, and plot the results on a graph.

In the case of solutions of solid substances the rotation varies both with the concentration and also with the solvent.

Experiment 331.—Determine the variation of the specific rotatory power of tartaric acid at several different concentrations, e.g. 20, 10, and 5 per cent solutions, and express the results on a graph.

C. Stereoisomeric Unsaturated Compounds

An essentially different type of stereoisomerism is met with in the case of certain unsaturated compounds. This isomerism occurs when the two monovalent radicals attached to the two carbon atoms between which a double linkage exists are different, e.g. abC:Cab, or abC:Ccd, or abC:Cac. For examples see fumaric and maleic acids (S.B. Chap. X, B), oleic and elaidic, erucic and brassidic acids (ibid. Chap. VI, B), cinnamic acids (ibid. Chap. XXVI, A2).

A pair of such stereoisomerides is usually formed when water is eliminated from an α-hydroxy acid, e.g. malic acid, or hydrogen bromide (chloride) is eliminated from compounds of the type of crotonic acid dibromide (chloride), or cinnamic acid dibromide (chloride). Cf. Exp. 334.

The two isomerides differ considerably as regards physical properties, and to a certain extent as regards chemical properties. As a rule, they can be separated by the differences in the solubilities of the compounds themselves or of their derivatives.

Experiment 332.—Fumaric acid from malic acid.

$$CO_2H{\cdot}CH_2{\cdot}CHOH{\cdot}CO_2H \rightarrow CO_2H{\cdot}CH{:}CH{\cdot}CO_2H + H_2O.$$

A quantity of malic acid is placed in a suitable retort, which is heated in an oil bath at 140–150° until water ceases to be given off. The remaining solid is crystallized from hot water; yield, theoretical.

Fumaric acid consists of small crystalline prisms which sublime on heating about 200°.

Experiment 333.—Maleic anhydride and maleic acid from malic acid.

A quantity of malic acid is treated with three times its weight of acetyl chloride in a reflux apparatus, and after the initial reaction has moderated is heated on a boiling water bath until the reaction mixture is clear. It is then fractionally distilled, and after the removal of acetic acid and excess of acetyl chloride, maleic anhydride passes over at about 210° and solidifies in the receiver as long crystalline needles. It is purified by crystallization from chloroform or by sublimation; m.p. 54°.

A portion of the maleic anhydride is boiled with water, yielding a solution which on cooling deposits fine crystals of maleic acid, m.p. 130°.

Experiment 334.—α-Bromoallocinnamic acid and α-bromocinnamic acid from cinnamic acid dibromide. (αβ-dibromo-β-phenylbutyric acid.)*

$$C_6H_5{\cdot}CHBr{\cdot}CHBr{\cdot}CO_2H \rightarrow C_6H_5{\cdot}CH{:}CBr{\cdot}CO_2H + HBr.$$

20 g. of cinnamic acid dibromide (Exp. 322) (1 mol) are covered with alcohol, and the theoretical amount (2 mols) of alcoholic potash solution (10–15 per cent) is added. The mixture is heated for about fifteen minutes, and is finally evaporated to dryness on a water bath.

The two stereoisomeric α-bromocinnamic acids are most readily separated by means of their barium salts, as barium α-bromocinnamate is practically insoluble in cold water, whereas barium α-bromoallocinnamate is readily soluble. The residue is mixed with water (it is not necessary to dissolve the potassium salts present completely), and a moderate excess of a 10 per cent barium chloride solution is added. The precipitated barium α-bromocinnamate is removed with the aid of a

* J. C. S. 1903, 83, 673.

porcelain funnel and washed several times with dilute barium chloride solution. The two acids are obtained by treating the precipitate and the filtrate separately with hydrochloric acid; the precipitated acids are filtered off, washed with water, and dried on porous plate. Yield of α-bromo acid, 1·5 g.; of α-bromo-allo acid, 11–12 g.

The α-bromocinnamic acid is crystallized from benzene, when it is obtained as colourless prismatic needles, m.p. 131°. The allo-acid crystallizes from light petroleum, or from a mixture of chloroform and carbon disulphide, as yellowish transparent prisms, m.p. 120°.

Almost invariably one of the two stereoisomers is less stable than the other; this is frequently termed the allo-compound, and may be transformed into the more stable compound by one or more of the following methods: (1) Exposure to sunlight for some weeks; (2) exposure to moderately high temperature; (3) treatment with small amounts of certain chemicals.

An example of the last method has been met with in Exp. 66, namely, the conversion of oleic acid, $CH_3(CH_2)_7{\cdot}CH{:}CH(CH_2)_7{\cdot}CO_2H$, into its stereoisomer elaidic acid by the action of nitrous acid.

α-Bromoallocinnamic acid may be transformed into the more stable α-bromo acid by either the first or second of the above methods.

Experiment 335.—Transformation of α-bromoallocinnamic acid into α-bromocinnamic acid.*

10 g. of α-bromoallocinnamic acid are placed in a boiling tube, a thermometer being immersed in the substance. The tube is heated in an oil bath until the thermometer indicates a temperature of 200–210°, and is kept at this point for about twenty minutes. The product after cooling is dissolved in dilute alkali, and after neutralization of excess of alkali the solution is treated with excess of barium chloride solution; the separation of the α-bromo acid from any residual allo-acid is carried out as indicated in the last experiment. Yield of α-bromocinnamic acid, 8–9 g.

Both of the bromo-acids lose hydrogen bromide when heated with alkaline solutions, and yield the acetylene derivative, phenylpropiolic acid, $C_6H_5{\cdot}C{:}C{\cdot}CO_2H$ (cf. Exp. 19). It is found, however, that the α-bromo-acid reacts with alkali much more readily than the allo-acid.

* *Sudborough* and *Thompson*, J. C. S. 1903, 83, 686.

Experiment 336.—Elimination of hydrogen bromide from α-bromocinnamic acid: Preparation of phenyl-propiolic acid. 10 g. of the α-bromo acid is heated for two hours on a boiling water bath with 20 per cent aqueous potassium hydroxide solution (2·5 mols). When cold the solution is filtered, if not quite clear, and then acidified with hydrochloric acid. The precipitate is removed, washed, dried, and recrystallized from a mixture of chloroform and light petroleum, when the phenyl-propiolic acid, $C_6H_5{\cdot}C{:}C{\cdot}CO_2H$, is obtained as colourless prismatic needles, m.p. 137°.

XXXIII. MOLECULAR REARRANGEMENT (S.B. Chap. XXXVIII)

Many organic compounds are changed under certain conditions into more stable isomerides, i.e. substances with the same molecular but different structural formulæ. As a rule these changes are non-reversible and in this respect differ from tautomeric changes. When the rearrangement takes place readily it is quite possible that during the preparation of a given compound it has become transformed into its more stable isomer.* The rearrangement always takes place with a decrease of free energy and in certain cases intermediate compounds can be detected.

The simplest type of rearrangement is where two groups attached to the same asymmetric carbon atom exchange places. The result is that an optically active compound containing one asymmetric carbon atom is changed to its antipode, and if this change takes place to the extent of 50 per cent the final product is a *dl*-mixture or a racemic compound. (Racemization, S.B. Chap. LXXI, I, 3.)

Analogous to this is the *Walden Inversion* (S.B. ibid. 4), where starting from the pure *d*- or *l*-compound it is possible by a series of comparatively simple reactions to obtain the optical antipode.

$$l\text{-chlorosuccinic acid} \xrightarrow[\text{moist } Ag_2O]{} l\text{-malic acid} \xrightarrow[PCl_5]{} d\text{-chlorosuccinic acid.}$$

* *C. W. Porter*, Molecular Rearrangements, New York, 1928.

Partial Racemization of Camphoric Acid.—Camphoric acid contains two dissimilar carbon atoms and hence exists in four optically active forms and two racemic forms, *d*- and *l*-camphoric acids which form a pair of enantiomorphs, and *d*- and *l*-*iso*-camphoric acids which form the second pair. A camphoric acid can be changed to an *iso*-camphoric acid by change in position of the groups attached to one of the two asymmetric carbon atoms only.

Experiment 337.—Conversion of + camphoric acid into −*iso*-camphoric acid.*

(*a*) *Preparation of camphoryl chloride.*—10 g. camphoric acid are heated with 20 ml. thionyl chloride in reflux apparatus for 30 minutes and the excess of thionyl chloride removed by heating on the water bath.

(*b*) *Preparation of the* iso-*camphoric acid.*—10 g. of camphoryl chloride are added very gradually to 200 g. of water at 80°, the liquid being continuously stirred mechanically. When all is added the mixture is immediately filtered and on cooling a crystalline deposit of −*iso*-camphoric acid is obtained. To purify, treat the dry acid with acetyl chloride to convert any +camphoric acid into its anhydride, evaporate off the excess of acetyl chloride and extract with cold sodium carbonate. On acidifying the alkaline liquid the *iso*-acid is obtained, and after crystallization from hot water has m.p. 172·5° and $[\alpha]_D = -46{\cdot}2$ in 10 per cent aqueous solution.

The rearrangement usually involves the migration of one or more radicals, and it is convenient to classify these migrations into the following groups:

A. Migration from N to C.
B. Migration from C to N.
C. Migration from C to C.
D. Migration from O to C.
E. Migration from S to C.

The rearrangements are sometimes classified as (i) *intramolecular* when the change takes place in the one molecule without involving a reaction with a second molecule, (ii) *intermolecular* when the change is due to a reaction with other molecules.

* *Marsh*, C. N. 1889, **60**, 307; *Walker* and *Wood*, J. C. S. 1900, 386. The signs and are used as indicating the dextro and laevo rotations of the two compounds.

A. Migration from N to C

This is one of the commonest types met with and is illustrated by the following examples:

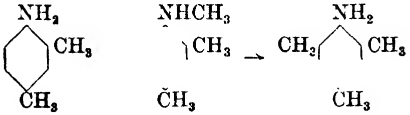
1. *The Hofmann Reaction.**—When the hydrochloride of an alphylarylamine is heated at 300° the alphyl wanders from the side chain N to the *o*- or *p*-carbon atom of the nucleus. Thus monomethylaniline hydrochloride yields *o*-toluidine hydrochloride,

$$C_6H_5NHMe \rightarrow CH_3{\cdot}C_6H_4{\cdot}NH_2.$$

In many cases it is not actually necessary to isolate the secondary amine, but to work with materials from which this can be formed, e.g. primary amine hydrochloride and methyl alcohol.

Experiment 338.—Transformation of methyl-*m*-xylidine, $C_6H_3Me_2{\cdot}NHMe$, **to mesidine,** $C_6H_2Me_3{\cdot}NH_2$.

Molecular proportions of *m*-xylidine hydrochloride (2:4-dimethylaniline hydrochloride) and methyl alcohol are heated in a sealed tube at 300° for twenty-four hours. When cold the product is dissolved in water, made alkaline with sodium hydroxide and extracted with ether. The ethereal solution is dried with solid potash, the ether removed, and the base distilled. Mesidine is a colourless oil, b.p. 229–230°.



2. The nitroso-group of an alphylarylnitrosamine migrates into the *p*-position when the nitroso-compound is treated with alcoholic hydrogen chloride. Thus nitrosomethylaniline yields *p*-nitrosomethylaniline:

$$C_6H_5{\cdot}NMe{\cdot}NO \rightarrow NO{\cdot}C_6H_4{\cdot}NHMe.$$

A nitramine behaves in a similar manner, thus phenylmethylnitramine yields *p*-nitromethylaniline.

Experiment 339.—*p*-Nitrosomethylaniline from methylphenylnitrosoamine.

$$C_6H_5{\cdot}N\begin{matrix}\diagup NO\\ \diagdown CH_3\end{matrix} \rightarrow NO{\cdot}C_6H_4{\cdot}NH{\cdot}CH_3.$$

* B. 1872, 5, 704.

1 part of methylphenylnitrosamine (Exp. 164) is dissolved in 2 parts by weight of ether, and 4 parts by weight of absolute alcohol saturated with hydrogen chloride are added. After some time a mass of crystalline needles separates. These are filtered and washed with a mixture of alcohol and ether, and then have m.p. 118°. The yield is theoretical.

3. The conversion of hydrazo-compounds into diphenyl derivatives under the influence of acids,

$$C_6H_5\cdot NH\cdot NH\cdot C_6H_5 \rightarrow p.\ NH_2\cdot C_6H_4\cdot C_6H_4\cdot NH_2\ p.,$$

e.g. hydrazobenzene into *pp'*-diaminodiphenyl (benzidine).

Experiment 340.—Conversion of hydrazobenzene into benzidine.*

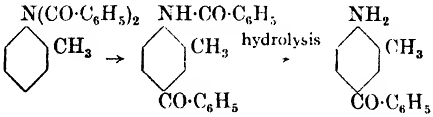
2 g. of hydrazobenzene (Exp. 264) are mixed with concentrated hydrochloric acid, and kept for five minutes at the ordinary temperature. Water is then added, and the mixture made alkaline by the addition of sodium hydroxide solution. The benzidine may be extracted with ether and crystallized from water, when it forms glistening plates, m.p. 128°.

4. The conversion of a diacylated arylamine into a *p*-monoacetylamino-derivative of an alphyl aryl or diaryl ketone:*

$$C_6H_5\cdot N(COC_6H_5)_2 \rightarrow C_6H_5\cdot CO\cdot C_6H_4\cdot NH\cdot COC_6H_5.$$

In this change it is not always necessary to isolate the diacylated amine.

Experiment 341.—Transformation of dibenzoyl-*o*-toluidine into benzoyl-4-amino-3-methyl-benzophenone. 4-Amino-3-methyl-benzophenone.



o-Toluidine (1 mol) is added gradually to the equivalent quantity of benzoyl chloride (2 mols), and the whole gradually heated in an oil bath to 220–230°, this temperature being maintained for about fifteen hours. A brown viscid liquid is produced which solidifies on cooling to a hard resinous mass. The benzoyl-4-amino-3-methyl-benzophenone can only be isolated from this product with some difficulty, so it is best

* *Chattaway*, J. C. S. 1904, 85, 386.

to hydrolyse it, as the corresponding base is more readily separated. The whole mass is dissolved in excess of alcohol, containing half its bulk of concentrated hydrochloric acid, and heated to boiling for fourteen hours. A rapid current of steam is blown through the product thus obtained, when alcohol and ethyl benzoate distil over successively. The strongly acid residue is boiled for some time with water, and the hot solution containing the hydrochloride of the base filtered from the brown tarry matter, which is always formed in considerable amount during the transformation. The filtrate is then made slightly alkaline, and again distilled with steam to remove any *o*-toluidine derived from untransformed dibenzoyl-*o*-toluidine. After cooling, the solid separating from the alkaline liquid in the distillation flask is filtered off and extracted with alcohol. This alcoholic solution is evaporated to a small bulk, and a few drops of strong sulphuric acid added; on diluting with a little ether, the almost pure base crystallizes in colourless needles. After recrystallization from water slightly acidified with sulphuric acid, it forms pale yellow prisms, m.p. 112°. Yield, 50 per cent of the weight of *o*-toluidine used.

5. The N-chlorinated acylarylamines readily isomerize in the presence of hydrochloric acid, yielding *o*- and *p*-chloro-derivatives of an acyl-arylamine.* N-chloro-acetanilide gives

$$C_6H_5{\cdot}NAcCl \rightarrow Cl{\cdot}C_6H_4{\cdot}NHAc$$

o- and *p*-chloracetanilide. The reaction does not consist in a simple migration of chlorine as the original compound reacts with hydrochloric acid liberating free chlorine which then chlorinates the nucleus in the *o*- and *p*-positions. The reaction is of the intermolecular type:

$$C_6H_5{\cdot}NClAc + HCl \rightarrow C_6H_5{\cdot}NHAc + 2Cl \rightarrow Cl{\cdot}C_6H_4{\cdot}NHAc + HCl.$$

Experiment 342.—(*a*) Acetchloranilide, $C_6H_5{\cdot}N(Cl)CO{\cdot}CH_3$, from acetanilide.

$$C_6H_5NH{\cdot}CO{\cdot}CH_3 + Cl_2 \rightarrow C_6H_5NCl{\cdot}CO{\cdot}CH_3 + HCl.$$

Acetanilide (Exp. 166) is suspended in excess of a solution of potassium bicarbonate, and the calculated quantity of bleaching powder solution added.† The product is extracted with

* *Chattaway* and *Orton*, J. C. S., 1899, **75**, 1046; 1900, **76**, **134**, **152**, **789**, **797**; *Raper*, *Thompson*, and *Cohen*, 1904, **85**, 371.

† The solution should be standardized by means of standard thiosulphate solution.

chloroform, and after recrystallization from a mixture of chloroform and light petroleum consists of large transparent plates, m.p. 91°. Yield, 96 per cent of theory.

The substance liberates iodine from an acid solution of potassium iodide.

$$C_6H_5N\langle\begin{matrix}Cl\\CO{\cdot}CH_3\end{matrix} + 2HI \rightarrow C_6H_5NH{\cdot}CO{\cdot}CH_3 + HCl + I_2.$$

(*b*) Determine the amount of iodine liberated by a known weight of the substance by dissolving in chloroform and shaking the solution with a solution of potassium iodide acidified with acetic acid; titrate the liberated iodine with 0·1 N. sodium thiosulphate solution.

(*c*) **Transformation of acetochloranilide to *p*-chloracetanilide.** This change occurs slowly on keeping the substance, and is complete in two or three weeks; it may be accelerated by the addition of acid.

The acetochloranilide is dissolved in warm dilute acetic acid, and crystals of *p*-chloracetanilide separate as the liquid cools. M.p. 172·5°.

6. The formation of amino-azo-compounds from diazo-amino-compounds (Exp. 190).

In this case also the reaction is not a simple migration but a series of reactions terminating in a coupling.

The reaction

$$\text{(i)}\quad C_6H_5{\cdot}N_2{\cdot}HSO_4 + H_2N{\cdot}C_6H_5 \rightleftharpoons C_6H_5{\cdot}N{:}N{\cdot}NHC_6H_5 + H_2SO_4$$

is reversible, so that in presence of acid the diazo-amino-compound yields a certain amount of diazonium salt and free base (or salt) which can then react as a normal coupling

$$\text{(ii)}\quad C_6H_5{\cdot}N_2X + H_2NC_6H_5 \rightarrow C_6H_5{\cdot}N_2{\cdot}C_6H_4{\cdot}NH_2$$

and is non-reversible.

7. The transformation of β-phenylhydroxylamine into *p*-aminophenol (Exp. 269):

$$C_6H_5{\cdot}NH{\cdot}OH \rightarrow p{\cdot}OH{\cdot}C_6H_4{\cdot}NH_2.$$

8. The formation of sulphanilic acid from aniline and sulphuric acid (Exp. 127). This involves a migration of the sulphonic group from N to C as phenylsulphamic acid, $C_6H_5{\cdot}NH{\cdot}SO_3H$, is first formed.

B. Migration from C to N

The best-known example of this type is the *Beckmann transformation of oximes* (S.B. Chap. XXXVIII, C).

1. *Beckmann transformation of oximes.*—Oximes (Chap. XXII, B) derived from aldehydes or unsymmetrical ketones usually exist in two stereoisomeric forms, viz. (i) and (ii), (iii) and (iv):

$$\text{(i)}\quad \begin{matrix} R\cdot C\cdot H \\ \ddot{N}\cdot OH \end{matrix} \qquad\qquad \text{(ii)}\quad \begin{matrix} R\cdot C\cdot H \\ HO\cdot\ddot{C} \end{matrix}$$

In (i) the H and OH are in *syn* or *cis* positions, and in (ii) in the *anti* or *trans* positions.

$$\text{(iii)}\quad \begin{matrix} C_6H_5\cdot C\cdot C_6H_4X \\ \ddot{N}\cdot OH \end{matrix} \qquad\qquad \text{(iv)}\quad \begin{matrix} C_6H_5\cdot C\cdot C_6H_4X \\ HO\ddot{N} \end{matrix}$$

The configuration of the oxime of an unsymmetrical ketone can be determined from the nature of the product obtained by the action of phosphorus pentachloride or sulphuric acid on the oxime (the Beckmann transformation). Under the influence of the dehydrating agent the OH changes place with the alkyl or aryl group in the *anti* or *trans* position.*

Thus (iii) gives (v) and (iv) gives (vi).

$$\text{(v)}\quad \begin{matrix} HO\cdot C\cdot C_6H_4X \\ \ddot{N}\cdot C_6H_5 \end{matrix} \qquad\qquad \text{(vi)}\quad \begin{matrix} C_6H_5\cdot C\cdot OH \\ C_6H_4X\cdot\ddot{N} \end{matrix}$$

Both these immediately change to their respective tautomeric forms,

$$C_6H_4X\cdot CO\cdot NH\cdot C_6H_5 \text{ and } C_6H_5\cdot CO\cdot NH\cdot C_6H_4X.$$

If X = Br, these compounds are respectively the anilide of bromobenzoic acid and the bromanilide of benzoic acid. It therefore follows that the oxime which yields the anilide of bromobenzoic acid will have the structure (iii), and that yielding the bromanilide of benzoic acid, structure (iv).

Experiment 343.—Transformation of *p*-methoxybenzophenone oximes.

A weighed amount of each of the two *p*-methoxy-benzophenone oximes (Exp. 216) is dissolved separately in anhydrous ether and treated gradually with 1·5 times its weight of phos-

* Beckmann considered the exchange to be with the *syn* or *cis* alkyl group, but Meisenheimer has shown this to be incorrect.

phorus pentachloride. After removal of the ether the residue is treated with water, the solid product is separated and crystallized from a little alcohol. Determine the m.p.'s of the products and hence deduce the configurations of the two oximes. The anilide of anisic acid, $OMe\cdot C_6H_4\cdot CO\cdot NHC_6H_5$, melts at 169° and the aniside of benzoic acid, $C_6H_5\cdot CO\cdot NH\cdot C_6H_4\cdot OMe$, at 154°.

2. *Decomposition of azides.*—Acid azides, $R\cdot CO\cdot N_3$, when heated lose nitrogen and yield alkyl *iso*-cyanates, R·N:C:O, involving a wandering of an alkyl group from C to N.

C. Migration from C to C

1. *Pinacol-pinacolone rearrangement.**—This is the most common example of a C to C migration. The $\alpha\beta$-glycol, obtained as a by-product in the reduction of a ketone to a secondary alcohol (p. 301), under the influence of sulphuric acid, loses water and yields a ketone,

$$OH\cdot CMe_2\cdot CMe_2\cdot OH \rightarrow CMe_3\cdot CO\cdot Me.$$

Experiment 344.—Conversion of pinacol into pinacolone.†
10 g. of anhydrous pinacol (Exp. 267) are added at 0° to 30 g. of concentrated sulphuric acid, and after a short time the mixture is poured on to ice, extracted with ether, dried and distilled, b.p. 106°.

2. *Benzil transformation.*—The α-diketone, benzil, $C_6H_5\cdot CO\cdot CO\cdot C_6H_5$, is quantitatively converted by aqueous alcoholic potash into benzilic acid, diphenyl-hydroxy-acetic acid, the reaction involving the addition of water and the wandering of a phenyl group from C to C:

$$C_6H_5\cdot CO\cdot CO\cdot C_6H_5 + H_2O \rightarrow (C_6H_5)_2C(OH)\cdot CO_2H.$$

Experiment 345.—Benzilic acid.‡
50 g. of potassium hydroxide and 100 g. of water are introduced into a flask containing 50 g. of benzil (Exp. 278), and after the alkali has dissolved, 100 g. of alcohol are added. The mixture is boiled on a water bath for not more than ten minutes, and the contents then poured into a beaker.

* The old names pinacone for the original glycol and pinacoline for the ketonic product are most misleading, hence the newer names pinacol for the glycol and pinacolone for the ketone are used.

† *Scholl* and *Schibig*, B. 1895, 1364; Org. Syn. 5, 87.

‡ *H. von Leibig*, B. 1908, 41, 1644.

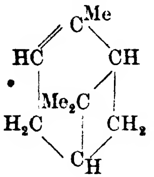
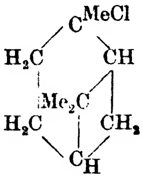
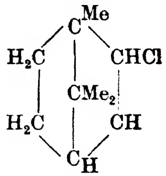
After some hours the crystals are removed on a hardened filter-paper, washed with alcohol, and then well stirred with 75 to 100 g. of cold alcohol. The crystals are removed, dissolved in from 0·5 to 1 litre of water, and the solution filtered and made up to 1 litre. The solution is then boiled, and boiling dilute sulphuric acid added, when a 90–95 per cent yield of acid is deposited. The crude acid can be recrystallized from boiling benzene, when it separates as colourless needles, m.p. 150°.

A similar reaction is the conversion of hydrobenzoin under the influence of sulphuric acid into diphenylacetaldehyde:

$$C_6H_5{\cdot}CH(OH){\cdot}CH(OH){\cdot}C_6H_5 - H_2O \rightarrow (C_6H_5)_2CH{\cdot}CHO.$$

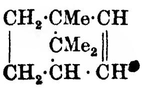
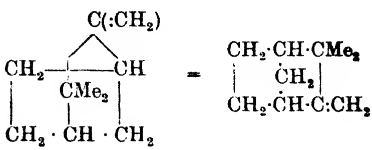
The yield is good, whereas under similar conditions benzoin, $C_6H_5{\cdot}CH(OH){\cdot}CO{\cdot}C_6H_5$ (Exp. 211), gives only a small yield of diphenylacetic acid.

3. *The Wagner-Meerwein rearrangement.*—A remarkable rearrangement occurs when the terpene, pinene, is treated with hydrogen chloride. Pinene (I) contains a double link in the ring, and the normal additive product would be a pinene hydrochloride (II) by the addition of H to the CH and Cl to the CMe group, and such a compound can be isolated by working at temperatures well below 0°.

I.  II.  III. 

By working at 0° the actual product is an isomeric hydrochloride, viz. bornyl chloride (III), the chloride corresponding with bornyl alcohol, borneol (see Exp. 50).

By the elimination of hydrogen chloride from bornyl chloride a second Wagner-Meerwein change occurs and the product obtained is not the expected bornylene (IV), but the isomeric camphene (V).

IV.  V. 

Experiment 346.—Conversion of bornyl chloride into camphene.

Equal weights of the chloride and aniline are warmed when the chloride dissolves. On further heating to about 180° the mass froths and solid aniline hydrochloride is formed. After cooling, the mixture is treated with excess of dilute hydrochloric acid and steam-distilled. A water-clear oil passes over and solidifies to a waxy mass, m.p. 49°.

D. Migration from O to C

1. *Urea transformation.*—The formation of urea, carbamide, from ammonium cyanate involves the breaking of an N·O link and the formation of a new N·C link:

$$H_4N{\cdot}O{\cdot}C{\vdots}N \rightarrow H_2N{\cdot}CO{\cdot}NH_2.$$

This change occurs when a solution of ammonium cyanate is boiled. The cyanate is prepared by oxidizing potassium cyanide or ferrocyanide to the cyanate by fusing with an oxidizing agent (usually a peroxide), and treating the extracted product with an ammonium salt.

Experiment 347.—Transformation of ammonium cyanate to urea (carbamide).

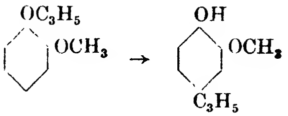
20 g. of dry potassium ferrocyanide are mixed with 7 g. of anhydrous potassium carbonate in an iron crucible or ladle, and fused in a blowpipe flame or fire. 36 g. of red lead are added gradually, and the mixture kept well stirred. When the whole of the red lead has been added, the fused mass is poured on to an iron tray, and after cooling is extracted with boiling water. The solution is filtered, and the filtrate treated with 20 g. of ammonium sulphate and evaporated to dryness on a water bath. The solid residue is broken up and extracted with hot alcohol, which dissolves the urea. When the alcoholic solution is evaporated crystals of urea are obtained. It may be purified by recrystallization from water, when it is deposited as colourless prisms, m.p. 132°.

The transformation in this case is not complete, but when the point of equilibrium is reached only a small amount of cyanate remains unchanged.

Urea is the diamide of carbonic acid, and as such shows the general properties of amides (S.B. Chap, IV, B). In addition, it possesses feebly basic properties; thus it forms a sparingly

soluble nitrate, $CO(NH_2)_2$, HNO_3, and oxalate, $CO(NH_2)_2$, $H_2C_2O_4$, $2H_2O$.

2. *Transformation of allyl ethers.*—Certain substituted aromatic allyl ethers, when heated to 230°, change into phenols with a *p*-allyl substituent. One of the best-known examples is the conversion of guaiacol-allyl-ether into 1-hydroxy-2-methoxy-4-allylbenzene:



The allyl ether of phenol behaves in a similar manner, and by repeating the process, viz. formation of ether and rearrangement, it is possible to prepare 2:4:6-triallylphenol.

3. *Kolbe's synthesis of aromatic hydroxy acids.*—*Kolbe's* synthesis of salicylic acid involves a migration of CO_2H from O to a C of the ring (cf. Chap. XII, G):

$$C_6H_5{\cdot}ONa + CO_2 \rightarrow C_6H_5{\cdot}O{\cdot}CO_2Na \rightarrow OH{\cdot}C_6H_4{\cdot}CO_2Na.$$

E. Migration from S to C

A transformation similar to that of ammonium cyanate (Exp. 347) occurs in the case of ammonium thiocyanate with the production of thiourea (thiocarbamide):

$$NH_4{\cdot}S{\cdot}C{\vdots}N \rightleftharpoons CS(NH_2)_2.$$

In this case the transformation is only partial, as equilibrium is attained after 45 minutes at 170°, and the mixture then contains only 25 per cent of thiourea. When thiocarbamide is fused it is partially converted into ammonium thiocyanate.

Experiment 348.—Transformation of ammonium thiocyanate to thiocarbamide.*

• 30 g. of ammonium thiocyanate are placed in a boiling tube, and a thermometer immersed in the substance, which is heated by means of an oil bath. The salt fuses at 147° to a yellowish liquid. The temperature is raised to 170°, at which point it is maintained for an hour. The melt is allowed to

* *Reynolds*, J. C. S. 1869, *22*. 1; *Reynolds* and *Werner*, ibid, 1903, **83**, 1.

cool, and is then extracted with 50 ml. of hot water. The solution is filtered and allowed to cool, when crystals of thiocarbamide separate. These are removed and recrystallized from a little hot water, when the thioamide is obtained as flat needles, m.p. 172°. It dissolves fairly readily in cold water, very readily in hot water and in alcohol, but is almost insoluble in ether or benzene. It forms a sparingly soluble nitrate, $CS(NH_2)_2, HNO_3$.

XXXIV. QUANTITATIVE EXPERIMENTS WITH CARBOHYDRATES

A. Estimation of the Concentration of a Glucose Solution by means of its Cupric Reducing Power.

When a solution of glucose is warmed with Fehling's solution a precipitate of cuprous oxide is obtained, and on this reaction is based a quantitative method for estimating the amount of glucose, viz. by observing the exact volume of the sugar solution required to decolorize 10 ml. of the Fehling's solution of known concentration.

Fehling's Solution.—Two distinct solutions are prepared, and equal volumes of these are mixed just before use. *Solution 1.*—69·28 g. of pure copper sulphate crystals are dissolved in water, 1 ml. of pure sulphuric acid added, and the whole made up to 1 litre. *Solution 2.*—350 g. of sodium potassium tartrate (Rochelle salt) are dissolved in about 700 ml. of water; the solution is filtered if necessary, mixed with a solution of 100 g. of pure sodium hydroxide (purified by alcohol), and the whole made up to 1 litre. Each ml. of the mixed solutions (equal volumes) should contain 0·03464 g. of cupric sulphate, and is equivalent to 0·005 g. of pure anhydrous glucose. The two solutions may be kept for some time without deteriorating, but it is advisable to standardize occasionally by means of pure sucrose (cane sugar). For this purpose a solution of 0·95 g. of pure sucrose in 50 ml. of water and 2 ml. of concentrated hydrochloric acid is heated at 70° for ten minutes, then neutralized with sodium carbonate

and made up to 1 litre with distilled water. By this process the cane sugar is hydrolysed to a mixture of equal quantities of glucose and fructose, both of which reduce Fehling's solution. The standardizing by means of this solution is accomplished in the same manner as the glucose estimations.

Titration of Glucose Solution with Fehling's Solution.— 5 ml. of each of the Fehling's solutions are measured by means of a calibrated pipette and placed in a small porcelain dish, 40 ml. of water are added, and the solution quickly heated to boiling. With good solutions no change in colour should occur; if any change is observed a second experiment is made by adding a little more sodium hydroxide solution before boiling.

Small amounts of the glucose solution are then run in from a burette, the mixture boiled, and the operations repeated until the blue colour of the solution is just discharged. The end point is most readily observed by tilting the dish slightly, so that the colour of the clear liquid free from the precipitate can be observed. This first titration can only be performed somewhat roughly, e.g. 1 ml. of sugar solution can be run in each time. The titration will give a rough idea of the concentration. 10 ml. of the Fehling's solution are equivalent to 0·05 g. of glucose, since each ml. of Fehling's solution contains 0·11 g. CuO, and 5 gram-mols of CuO oxidize 1 gram-mol of $C_6H_{12}O_6$. If it is found that the solution contains more than 1 per cent of glucose it must be diluted until the concentration is between 0·5 and 1·0 per cent, as reliable and comparable results can be obtained with solutions of such concentrations only. Several titrations are made and the mean taken.

Points to notice are:

1. The Fehling's solution must not be exposed for a long time to the air, and must not be unnecessarily heated, hence the need for making a preliminary rough titration in order to determine approximately the right amount of sugar solution required. In the subsequent titrations nearly the correct amount of sugar solution is added at first, the solution boiled, and then more sugar solution added drop by drop.

2. The concentration of the sugar solution is an important factor, and comparable results can only be obtained by using solutions of about the same concentration, e.g. 0·5–1 per cent, as recommended above.

Alternative Method.*

The hot solution of sugar is mixed with excess of Fehling's solution and immersed in a boiling-water bath for fourteen minutes. The solution is then filtered, using a Hirsch porcelain funnel (fig. 13*b*), the plate of which is covered with a layer of fine asbestos. The liquid is sucked through with the aid of the pump, and the precipitated cuprous oxide washed with hot water until free from alkali. The oxide is then dissolved in a known volume of acidified standard permanganate solution, e.g. 25 ml. of 0·2 N. permanganate and 100 ml. of 25 per cent sulphuric acid, if the amount of oxide does not exceed 0·2 g. Boiling water is added to raise the temperature to 45–50°, an excess of 0·2 N. oxalic acid is run in and the excess titrated by means of the standard permanganate.

For a 0·2 N. solution of permanganate each ml. used corresponds with 0·01426 g. of cuprous oxide, since $Cu_2O + O \rightarrow 2CuO$, or with 0·01426 × 0·5045 g. of glucose.

The cuprous oxide may also be estimated by filtration, washing, and oxidizing to cupric oxide or reducing to metallic copper, and weighing as such.

B. Sucrose (Cane Sugar)

Sucrose may be estimated by the above process after it has been hydrolysed or "inverted" by acids to the mixture of glucose and fructose known as invert sugar. Each ml. of Fehling's solution is equivalent to 0·00475 g. of sucrose.

A mixture of glucose and sucrose may be analysed by first determining the glucose, then hydrolysing another portion and determining the glucose and invert sugar.

Other sugars may be estimated by a similar method. 1 ml. of Fehling's solution is equivalent to 0·005 g. of glucose, fructose, or galactose, 0·00678 g. of milk sugar, or 0·00807 g. of maltose.

C. Polarimetric Estimation of Sugars

Estimation of Glucose.

Glucose has a specific rotatory power† $[\alpha]_D = +52{\cdot}7$. Since $[\alpha]_D = \dfrac{100a}{l{\cdot}c}$, where c = number of grams of glucose in

* *Caven* and *Hill*, J. S. C. I. 1897, **16**, 981; 1898, **17**, 124. † See p. 353.

100 ml. of solution, α = the rotation observed for such a solution, and l = length of tube, i.e. length of layer of liquid used in decimetres, it is easy to calculate c when all the other factors are known.

10 g. of the crude glucose are made up to 100 ml. with water, the solution heated,* then cooled, and the rotation observed in a 200 mm. tube.

Sucrose has a value $[\alpha]_D = +66{\cdot}5°$, and the concentration of a solution can be determined in the same manner as with glucose.

A mixture of both glucose and sucrose can also be determined polarimetrically. The method consists in taking a polarimetric reading of the solution before inversion, and again after inversion (hydrolysis).†

The sucrose can be calculated from the formula:

$$P = \frac{\alpha - 2\alpha'}{m}.$$

Where α is the number of divisions indicated by the polarimeter scale for 200 mm. of the original solution, α' is the same factor for the inverted solution, and m = the number of divisions of the polarimeter scale which 200 mm. of a solution containing 1 g. of cane sugar per 100 ml. alters on inversion, and P = number of grams of cane sugar present in the original solution.

The rotation due to this amount of cane sugar is subtracted from the initial rotation, and the difference gives the rotation due to the glucose present.

The specific rotatory powers of some of the commoner carbohydrates are:

Sucrose	+ 66·5	*d*-Fructose	− 95·5
Maltose	+ 139	Invert sugar	− 21·5
Lactose	+ 52·5	*d*-Galactose	+ 80·3
d-Glucose	+ 52·7		

* This is essential, as glucose exhibits the property of mutarotation (S.B. Chap. LXXI, I, 2), and a constant value for the rotation can only be obtained after heating or treatment with alkali.

† See p. 374.

XXXV. QUANTITATIVE EXPERIMENTS WITH ACIDS, ESTERS, AMINES, ETC.

A. Estimation of the Amount of Free Acid and of Ester in a Mixture

A small amount of the mixture is weighed, dissolved in water or alcohol, and carefully titrated with standard alkali, preferably barium hydroxide, using phenolphthalein as indicator. The end point is usually very sharp, but if the ester present is readily hydrolysed the pink coloration will disappear after a minute or two. From the results of several titrations the percentage of acid in the mixture can be calculated, provided it is known what particular acid is present. To determine the ester a known weight of the mixture is boiled for some time with an excess of standard alkali solution in a flask * provided with a reflux condenser, care being taken that atmospheric carbon dioxide is excluded. When the hydrolysis is complete the excess of alkali is titrated with standard acid (hydrochloric or oxalic). The total volume of alkali taken − alkali left after hydrolysis = alkali required to neutralize the free acid and to hydrolyse the ester. The amount required to neutralize the acid in a given weight of mixture is already known, the amount of alkali required to hydrolyse the ester in the given weight of mixture is determined by difference, and hence the weight of ester in the mixture can be calculated, provided it is known what particular ester is present.

A mixture containing acid, ester, and alcohol can be analysed in a similar manner; the amounts of acid and ester are determined, and the amount of alcohol calculated by difference.

B. Estimation of the Amounts of each of Two Acids Present in a Mixture when one is Volatile in Steam and the other not, e.g. mixture of Acetic and Oxalic Acids.

A given weight of the mixture is steam-distilled until the distillate is no longer acid. The distillate and the residue in the flask are separately titrated with standard barium hydroxide, using phenolphthalein as indicator.

* Resistance flasks are best for this purpose as the glass is practically unacted upon, whereas ordinary glass is readily attacked by caustic alkalis.

C. Estimation of the Amounts of a Primary and Tertiary Amine in a Mixture of the Two, e.g. Aniline and Dimethylaniline.

(*a*) The primary amine may be estimated by adding an excess of acetic anhydride gradually to a known weight (about 10 g.) of the mixture, warming for a few minutes and then distilling under reduced pressure. The excess of acetic anhydride, the acetic acid, and tertiary amine distil over and the temperature then rises suddenly. The distillation is stopped, and the acetyl derivative of the primary amine weighed; this is readily accomplished if the weight of the distilling flask is known.

(*b*) If the primary amine is an arylamine it may be titrated with standard sodium nitrite (cf. Chap. XVIII, F), or may be diazotized and the nitrogen evolved by heating the diazonium salt measured (XXXVI, D).

D. Estimation of a Mixture of two Acids by Indirect Analysis

(*a*) *By titration.* A given weight of the mixture or a given volume of solution containing a known weight of the mixed acids is titrated with standard barium hydroxide.

(*b*) By determination of the percentage of one constituent, e.g. in a mixture of pure mono- and tri-chloracetic acids, a chlorine determination will give the data necessary for estimating the amounts of the two acids by indirect calculation.

E. Estimation of a Mixture of an Acid and its Acid Anhydride, e.g. Acetic Acid and Acetic Anhydride

Both acid and anhydride react with the alkali according to the equations

$$CH_3{\cdot}COOH + NaOH \rightarrow CH_3{\cdot}COONa + H_2O,$$

and

$$(CH_3{\cdot}CO)_2O + 2NaOH \rightarrow 2CH_3{\cdot}COONa + H_2O.$$

The amount of standard alkali required to neutralize a given weight of the mixture is determined when phenol phthalein is used as indicator, and the percentages of the two found by indirect calculation.

F. Estimation of a Mixture of an Acid and an Acid Amide, e.g. Oxalic Acid and Oxamide

The free acid is estimated by titration, using an alcoholic solution. The acid amide can be estimated by hydrolysing with potash, collecting the ammonia in a given volume of standard acid, and titrating the excess of acid as in the ordinary estimation of ammonium salts.

G. Estimation of a Mixture of an Acid and an Amine, e.g. Benzoic acid and *p*-Toluidine

The acid may be determined by dissolving a given weight of the mixture in alcohol and titrating with standard barium hydroxide, using phenolphthalein as indicator. If the amine is a strong base, e.g. NMe_3, the acid cannot be determined by direct titration, but by distillation with alkali the amine can be estimated, and the distillate by direct titration with standard acid using methyl orange as indicator.

If a known volume of standard alkali is used for the distillation, the acid present can be estimated by titrating the excess of alkali in the residue.

To estimate the amine a given weight of the mixture (5–10 g.) is dissolved in ether, the acid removed by shaking the ethereal solution with sodium carbonate solution, and the amine transformed into its acetyl derivative by adding an excess of acetic anhydride to the ethereal solution. The ether is distilled over, and then the acetic acid and excess of acetic anhydride under reduced pressure, and the weight of the residual acetyl derivative determined.

H. Estimation of a Mixture of an Acid and an Aldehyde, e.g. Acetic Acid and Acetaldehyde

The free acid is estimated by direct titration with standard alkali (preferably sodium hydroxide) and the neutralized solution is then diluted to a known volume until it is approximately 0·5 per cent.* 25 ml. of this solution is added gradually to 50 ml. of a solution of potassium bisulphite (12 g. $KHSO_3$

* The solution must be dilute, otherwise in the subsequent titrations the hydriodic acid formed will interfere.

per litre). The flask is corked and kept for about 0·25 hour, and then titrated with 0·1 N. iodine solution. This gives the amount of sulphite which has not combined with the aldehyde.* 50 ml. of the original sulphite are titrated, and the difference gives the amount which has combined according to the equation

$$R{\cdot}CHO + KHSO_3 \rightarrow RCH(OH)(OSO_2K).$$

If the aldehyde is insoluble in water a small amount of alcohol may be added, but care must be taken that too large a quantity of solvent is not used, as the blue coloration of iodide of starch is not obtained in the presence of much alcohol.

J. Estimation of a Mixture of Alcohol and Hydrocarbon, e.g. Ethyl Alcohol and Benzene

A known weight of the mixture is boiled in a reflux apparatus for 10 minutes with an excess of a standard solution of acetic anhydride in benzene. Water is afterwards added and the free acetic acid titrated in the cold with standard alkali $(BaOH)_2$, using phenolphthalein as indicator.

K. Estimation of Phenol in an Aqueous or Benzene Solution †

50 ml. water, 5 ml. hydrochloric acid (sp. gr. 1·2), and 15 ml. phenol solution which must not be stronger than 0·1 N.‡ are placed in a stoppered bottle and a 0·1 N. bromide-bromate solution (2·76 g. of pure potassium bromate accurately weighed, and 15 g. of potassium bromide per litre) is added with continuous shaking at 22° until the contents exhibit a slight yellow colour. After further shaking for 1–2 minutes 0·5 ml. of a 20 per cent potassium iodide solution is added, and the iodine liberated by the excess bromine titrated with standard thiosulphate solution.

$$KBrO_3 + 5KBr + 6HCl \rightarrow 6KCl + 3H_2O + 6Br$$
$$C_6H_5{\cdot}OH + 6Br \rightarrow C_6H_2Br_3(OH) + 3HBr.$$

* *Ripper*, M. 1900, **21**, 1079; *Rocques*, C. N. 1900, **79**, 119.

† *Redman*, *Weith* and *Brock*, J. Ind. Eng. Chem. 1913, 389.

‡ If a preliminary experiment proves the solution to be stronger, it must be sufficiently diluted and another determination made.

Thus each ml. of 0·1 N. bromate-bromide solution corresponds with 0·0016 g. phenol.

It is essential that the phenol should be free from other substances which react with bromine, e.g. unsaturated compounds, other phenols, furfuraldehyde, &c.

L. Estimation of Furfuraldehyde in Aqueous Solution by Standard Bromine Solution *

A molecule of furfuraldehyde reacts with 4 atoms of bromine. It can be estimated in dilute aqueous solution by adding an excess of standard bromate-bromide mixture in the presence of acid and estimating the excess of bromine as indicated in the previous experiment.

M. Estimation of Formic Acid in Mixtures of the Acid with its Homologues †

Estimation of formic acid in an aqueous solution containing formic and acetic acids.—The formic acid is determined by the amount of standard permanganate required to oxidize it in the presence of sodium carbonate, and the acetic acid by determining the total acid by titration and subtracting the formic acid found. Solutions required are (1) potassium permanganate 5 g. per litre, (2) sodium carbonate 50 g. per litre, (3) ferrous ammonium sulphate 20 g. and sulphuric acid 30 g. per litre, and (4) sulphuric acid 50 per cent by volume.

40 ml. of the sodium carbonate and 20 ml. of the permanganate are placed in each of two flasks, and to one is added 0·05 g. of the material to be examined dissolved in a little water, the same quantity of water being added to the other. The flasks are warmed in the water bath during three minutes, cooled, and 20 ml. of sulphuric acid solution and 50 ml. of the ferrous solution added to each. The excess of ferrous ammonium sulphate is then estimated in each by means of the permanganate solution. The difference in the amounts used represents the amount of formic acid in the material. Each ml. of permanganate is equivalent to 0·00351 g. of formic acid. For very small amounts solutions used may be diluted 10 times.

* *Powell* and *Whittaker*, J. S. C. I. 1924, 36T.

† *Fouchet*, Bul. Soc. 1912 [iv], 11, 325.

N. Estimation of Formaldehyde in Formalin *

A sample of about 3 g. is carefully weighed and introduced into a flask provided with a ground-in stopper. 50 ml. of N. sodium hydroxide solution are added and well mixed, and then 50 ml. of 3 per cent hydrogen peroxide are run in through a funnel during 3 minutes and with occasional shaking of the flask. It is then stoppered and allowed to stand for 10 minutes, when the excess of alkali is titrated with N. sulphuric acid, using azolitmin as indicator:

$$H{\cdot}CH{:}O + H_2O_2 + NaOH \rightarrow H{\cdot}COONa + 2HO.$$

Each gram-mol of alkali used corresponds with a gram-mol of the aldehyde, but corrections must be made for the acid present in the formalin and hydrogen peroxide used.

O. Estimation of Acetone in the Presence of Ethyl Alcohol †

With aqueous sodium hydroxide both alcohol and acetone react with iodine, yielding iodoform, but with calcium hydroxide only the acetone reacts.‡

A measured amount of the solution containing about 0·05 g. of acetone is placed in a flask, 300 ml. of calcium hydroxide solution are added, the flask closed loosely with a rubber stopper and heated at 35°. 40 ml. of 0·2 N. iodine are added drop by drop in portions of 5 ml. and the flask shaken for 5 minutes after each addition. Ten minutes after the final addition of iodine the mixture is cooled, starch solution and 15 ml. of N. sulphuric acid added, and the excess of iodine titrated with 0·1 N. thiosulphate solution. 1 ml. of 0·2 N. iodine corresponds with 0·00193 g. acetone.

* *Mach* and *Herrmann*, A. 1923, **431**, 301.

† *Rakshit*, Analyst, 1916, 245.

‡ The reaction with alcohol is very slight, but with 100 parts of alcohol to 1 of acetone the results obtained are only approximate, owing to this action. Each ml. of alcohol uses 0·8 ml. of the iodine solution.

XXXVI. VELOCITY OF SOME TYPICAL ORGANIC REACTIONS

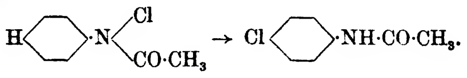
Numerous organic reactions proceed comparatively slowly, and it is an easy matter in many of these cases to determine the velocity constant of the reaction. The determination of the constant is based on Guldberg and Waage's Law of Mass Action, according to which the rate at which a reaction proceeds at a given temperature (i.e. the amount transformed in unit time) depends upon the concentration (in gram-molecules per litre), and upon a constant K which is characteristic of that reaction. Thus if a chemical reaction takes place between three substances, A, B, and C, in a given solvent, one molecule of each reacting and forming two new compounds, D and E,

$$A + B + C \rightarrow D + E.$$

Then if the initial concentrations be a, b, and c respectively, the rate at the beginning is denoted by $K \cdot a \cdot b \cdot c$. After the lapse of time t, if x gram-molecules of A, B, and C have reacted, the concentrations will be $a - x$, $b - x$, and $c - x$, and the rate will then be $K(a - x)(b - x)(c - x)$.

In this chapter a description is given of the methods used to determine K in the cases of some fairly simple organic reactions.

The simplest type of reaction is that in which one molecule only is involved, and a good example of this is the conversion of acetochloranilide into the isomeric *p*-chloracetanilide (cf. Exp. 342).*



Starting with a solution containing a gram-molecules of the chloranilide per litre, the velocity at the beginning is $K \cdot a$. After time t, when x gram-molecules have become transformed, the concentration is $a - x$, and the reaction then proceeds at the rate $K(a - x)$, assuming that the temperature remains constant. The differential equation is thus

$$\frac{dx}{dt} = K(a - x),$$

* *Blanksma*, Rec. 1902, **21**, 366; 1903, **22**, 290.

and when this is integrated we obtain the equation

$$K = \frac{1}{t} \log_e \frac{a}{a - x},$$

$$\text{or } K = \frac{2 \cdot 302}{t} \log_{10} \frac{a}{a - x}. \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This equation may be written in the form

$$K = \frac{2 \cdot 302}{t_2 - t_1} \log_{10} \frac{a - x_1}{a - x_2}, \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where x_1 and x_2 denote the number of gram-molecules transformed at the end of the intervals of time t_1 and t_2.

Such a reaction as the above is termed a *unimolecular* or *monomolecular* reaction, or a reaction of the *first order*. The above equation holds good for all such reactions, and the only difficulty is the determination of the concentration of the solution at the beginning and after given intervals of time. In the above example this is extremely simple, as the original acetochloranilide liberates iodine from a solution of potassium iodide, whereas the transformed product does not. The concentration is thus determined by adding an excess of potassium iodide to known volumes of the solution after given intervals of time, and titrating the liberated iodine by means of standard sodium thiosulphate, using starch solution as indicator.

It is not necessary to introduce the actual concentrations in gram-molecules into the equations 1 and 2; as we are dealing with the ratio $\log \frac{a}{a - x}$, we may simply substitute for a the number of ml. of thiosulphate required at the beginning of the reaction, and for $a - x$ the number of ml. required after time t (in hours). The results are usually tabulated as follows:

ours)	$a - x$ (ml. of thiosulphate)	$K = \frac{1}{t} \log \frac{a}{a - x}$
0	49·30	—
1	35·60	0·139
2	25·75	0·140
3	18·50	0·140

In the determination of the velocity constant it is essential that the temperature should remain constant, as a slight rise or fall in temperature affects the rate to a considerable extent; in certain reactions a rise of 5° will double the velocity. In

order to attain a constant temperature the vessels in which the reaction is proceeding are placed in a thermostat. The commonest form is a large water bath kept automatically stirred by means of a small water turbine, hot-air motor, or electric motor. The water is heated to the required temperature, and is kept at this temperature by means of a regulator. One of the best is an Ostwald toluene regulator (fig. 96).

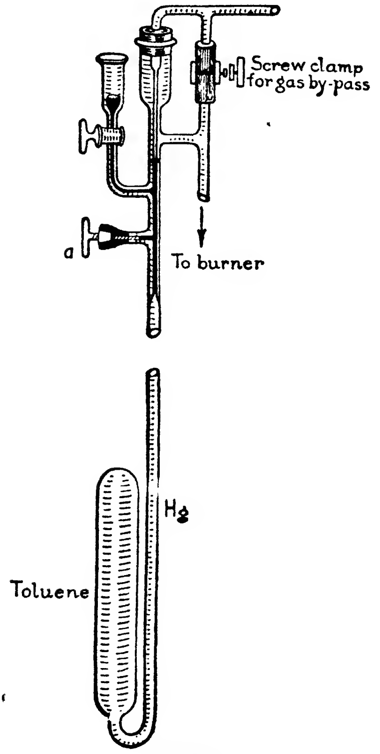


Fig. 96

This is filled with pure toluene; pure mercury is added, and the connexions with the gas and burner made by rubber tubing, which is wired on. The regulator is placed in the bath and the correct temperature obtained by exactly adjusting the mercury by means of the screw *a*. When properly adjusted the temperature can be kept constant for weeks. If impure mercury or toluene is used, the toluene shows a tendency to creep through the mercury. If the temperature rises slightly, the volume of the toluene increases and the mercury shuts off the gas supply from the burner, with the exception of a small amount which is admitted by means of the by-pass regulated by the screw clamp. As soon as the temperature falls, the mercury drops and lets through a larger gas supply. Lowry * suggested placing the toluene in a glass tube wound in a spiral round the upright tube containing the mercury. As thus arranged the regulator is much more sensitive.

* J. C. S. 1905, 87, 1030.

The same type of regulator can be used for an electrically heated bath.

Various reactions in which several molecules are involved can be regarded as unimolecular, provided large excesses of all the reacting substances but one are used. Thus, in the hydrolysis of cane sugar by mineral acids, the reaction consists in the addition of water to the cane sugar molecules, and the acid acts as a catalyser.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6.$$

If a very dilute solution of sugar is used, then the alteration in the amount of water present is so extremely small that we may regard the concentration of the water as remaining constant, and the only alteration is the concentration of the cane sugar.

Equation (1) or (2) may then be used for the determination of K, the concentrations $a - x$ at different intervals of time being determined polarimetrically (see Chap. XXXIV). It is not necessary to determine the absolute concentration of the cane sugar. If r_0 is the rotation at the beginning and r_∞ the rotation after complete hydrolysis, then $r_0 - r_\infty$ can be substituted for a, and $r_t - r_\infty$ for $a - x$, where r_t is the rotation at end of time t.

Other examples of the same type are given in Sections A and D.

When two molecules are involved in the reaction, then the alteration in concentration of each has to be taken into account. One of the simplest cases is where the initial concentrations of the two substances are the same. In the reaction,

$$CH_3{\cdot}CO{\cdot}OC_2H_5 + KOH \rightarrow CH_3{\cdot}CO{\cdot}OK + C_2H_5OH,$$

we start with a gram-molecules of ester and a gram-molecules of potassium hydroxide in 1 litre of solution. After time t, x gram-molecules of each will have disappeared, and the concentration will then be $a - x$ for each.

The rate of reaction is then $K(a - x)(a - x)$ or $K(a - x)^2$.

The differential equation is $\frac{dx}{dt} = K(a - x)^2$, and this on integration gives

$$K = \frac{1}{t} \cdot \frac{x}{(a - x)a}. \qquad \ldots \ldots \quad (3)$$

The concentrations corresponding with a, x and $a - x$ are

determined after given intervals of time t and substituted in the equation, and practically constant values for K are obtained. If equimolecular quantities are not taken the equation is somewhat different. In the hydrolysis of ethyl acetate if the concentration of the ester be a grams per litre and that of the potassium hydroxide be b grams per litre, then after time t the respective concentrations are $(a - x)(b - x)$, the differential equation is $\frac{dx}{dt} = K(a - x)(b - x)$, and this on integration gives

$$K = \frac{1}{t(a - b)} \log_e \frac{b(a - x)}{a(b - x)},$$

$$\text{or} \quad K = \frac{2{\cdot}302}{t(a - b)} \log_{10} \frac{b(a - x)}{a(b - x)}. \quad \ldots \ldots \quad (4)$$

The constants cannot be calculated by means of the simple formulæ (1) to (4) when the action is reversible.

A. Determination of the Rate of Esterification of an Organic Acid in presence of Hydrogen Chloride.

Pure methyl or ethyl alcohol is required. (For Purification, cf. Exp. 23.)

Some 250 ml. of a standard solution of hydrogen chloride in the alcohol is prepared by passing the dry gas (cf. Chap. XXXVIII, A) into a given weight of the alcohol until it has increased in weight to the required extent, taking care that moisture is excluded. One of the best methods of conducting this operation is to make use of a chlorinating vessel. The solution is afterwards carefully standardized by means of barium hydroxide solution (Chap. VII, I, A). If too concentrated, the solution can be diluted with pure alcohol. Usually a 0·1 N. or 0·025 N. solution is required.

A 0·1 N. solution of the organic acid is prepared by weighing out the theoretical amount of the pure dry acid, and making up to 100 ml. with pure alcohol. This solution is also carefully titrated with the standard barium hydroxide solution, using phenolphthalein as indicator. The two solutions are kept at 15°, and then 70 ml. of the hydrogen chloride solution is mixed with 70 ml. of the organic acid solution, and the time carefully noted. Four separate lots of 30 ml. each of the mixture are run

into four small stoppered bottles, which are immediately placed in the thermostat; the contents are titrated, after given intervals of time, by means of the standard barium hydroxide. The reaction may be regarded as a unimolecular one, since the alcohol is present in very large excess.

$$R{\cdot}OH + R'{\cdot}CO_2H \rightarrow R'{\cdot}CO_2R + H_2O.$$

The reaction is practically non-reversible, and the concentration of the alcohol may be regarded as remaining constant. The amount of water produced is comparatively small, and affects the constant to a very slight extent only.

Equation (1) is made use of for calculating the constant. The concentrations, a and $a - x$, may be represented by the number of ml. of standard barium hydroxide required to neutralize the organic acid present in 30 ml. of the solution immediately after mixing, and after the lapse of t hours respectively. The value a is obtained by titrating 15 ml. of the original solution of the organic acid, and the value $a - x$ by taking the total number of ml. of baryta required to neutralize the 30 ml. of mixture after time t, and subtracting the amount required for the hydrogen chloride present. The hydrogen chloride at 15° or 20° reacts so slowly with the alcohol that for all practical purposes its concentration may be regarded as remaining constant throughout the experiment.

The results are best tabulated in the following form:

t in hours.	f total no. of ml. of baryta required for the HCl and organic acid.	g ml. of baryta required for the HCl.	$a - x$ $(= f - g)$ ml. of baryta required for the organic acid.	$K = \frac{1}{t} \log \frac{a}{a - x}$

As the rate of esterification in the presence of pure alcohol is directly proportional to the concentration of the hydrogen chloride, the constant obtained should be divided by the concentration (normality) of the hydrogen chloride, and the constant thus obtained will give the esterification constant for normal hydrogen chloride.

Some general points of interest are:

1. The velocity increases rapidly with the temperature; a rise of 5° nearly doubles the constant.

2. The constant for ethyl alcohol is always less than for methyl; the two values stand in about the ratio 1 : 25.

3. The constant is very different for different types of acids. The fatty acids are esterified very readily. When methyl alcohol and a temperature of 15° are used, the concentration of the hydrogen chloride should be about 0·01 N. and the titrations should be made about every six to ten minutes.

Benzoic acid and its derivatives are esterified extremely slowly, and titrations may be made every twenty-four hours, using 0·1 N. hydrogen chloride. An unsaturated acid with a double bond in the $\alpha\beta$-position is esterified much less readily than the corresponding saturated acid, e.g. crotonic, $CH_3{\cdot}CH{:}CH{\cdot}CO_2H$, and cinnamic acid, $C_6H_5{\cdot}CH{:}CH{\cdot}CO_2H$, can be titrated every two or three hours, using 0·05 N. hydrogen chloride.

Substituents in the α- or ortho-positions with respect to the carboxylic group retard the esterification to an appreciable extent.

Experiment 349.—Determine the esterification constants of phenylacetic and cinnamic acids at 15° C., using methyl alcohol.

B. Determination of the Rate of Addition of Bromine to an Unsaturated Acid

One of the best media to use is carbon tetrachloride, as most of the acids dissolve in this, and it is not attacked by bromine. The carbon tetrachloride should be washed with acid and alkali if necessary, and then with water, and dried first over granular calcium chloride, and finally distilled over phosphoric anhydride. The bromine should be pure, as certain impurities, e.g. iodine, affect the rate of addition to an appreciable extent. The bromine may be shaken up with concentrated sulphuric acid in a separating funnel, the lower layer of bromine run off and placed in a freezing mixture of ice and calcium chloride. The bromine solidifies, and liquid impurities can be decanted off; the operation is repeated until the melting-point of the bromine is −7°.

The reaction is very susceptible to catalysts, and the conditions of the experiment must be rigidly controlled. The best catalyst is hydrogen bromide, which being slightly soluble in carbon tetrachloride can be added to the bromine solution in definite amount when this is made up.

The solution of hydrogen bromide is made by bubbling the dried gas into carbon tetrachloride (well protected from access of moisture) and estimating the amount of acid in a known volume of the solution by titration with standard alkali.

Solutions of the bromine containing a known amount of hydrogen bromide, and of the organic acid in carbon tetrachloride, are prepared and accurately standardized, the bromine solution by adding an excess of aqueous potassium iodide solution, and titration of the liberated iodine by means of standard sodium thiosulphate, using starch as an indicator, and the acid solution by means of standard barium hydroxide solution, using phenolphthalein as indicator. It will facilitate the calculation if the two solutions are of exactly the same strength, e.g. $\frac{1}{30}$ of a gram-molecule per litre.

Definite volumes (20 ml.) of the bromine solution are run out by means of a burette into small dry bottles, say six. To each of these is added an equivalent volume of the unsaturated acid solution *in the dark.** The time of mixing is carefully noted in each case, and the bottles (carefully stoppered) are placed in a thermostat at 15° or 20° and kept in the dark. After given intervals of time, the contents of the bottles are mixed with an excess of aqueous potassium iodide solution and titrated with the thiosulphate. The time allowed varies with different acids, but with an $\alpha\beta$-unsaturated acid such as crotonic, $CH_3\cdot CH{:}CH\cdot CO_2H$, or cinnamic, $C_6H_5\cdot CH{:}CH\cdot CO_2H$, one titration every twenty-four hours will suffice.

The reaction

$$C_6H_5\cdot CH{:}CH\cdot CO_2H + Br = C_6H_5\cdot CHBr\cdot CHBr\cdot CO_2H$$

is a bimolecular one, and the velocity of the reaction can be calculated by means of equation (3) (p. 385) if equimolecular solutions are employed, or equation (4) if the concentrations of the two solutions are different.

The concentration of the solution as regards bromine at time t is determined by the addition of a slight excess of potassium iodide solution and titration with the standard thiosulphate, and as one molecule of bromine reacts with one of the acid the concentration of the acid solution will diminish at the same rate as that of the bromine. If only a relative and not the actual constant is required, the number of ml.

* If a dark room is not available, amber-brown bottles may be used, and the solution transferred to a colourless bottle for titration.

of standard thiosulphate can be used to denote the concentrations.

It is advisable that the thiosulphate solution should be freshly standardized before use, and it is best kept from contact with atmospheric carbon dioxide in the same way as barium hydroxide solution.

Experiment 350.—Compare the rates of addition of bromine to cinnamic and crotonic acids at 20°.

Note.—With acids containing the olefine link in positions other than the $\alpha\beta$ the addition is so rapid that accurate determinations cannot be made.

C. Determination of the Rate of Addition of Iodine to an Acetylenic Acid in Aqueous Solution.*

Experiment 351.—Pure phenylpropiolic acid is converted into its potassium salt by dissolving in water containing the theoretical amount of potassium carbonate, and the solution is diluted until it contains 0·1 gram-molecule per litre. A 0·2 N. solution of iodine in potassium iodide is also prepared and accurately standardized by means of sodium thiosulphate. The two solutions are kept at 15° for a short time, and then equal volumes (75 ml. of each) mixed in the dark,† and the time noted. 20 ml. of the mixture is run into each of six small bottles which are kept in a thermostat (15°) in a dark room and the contents titrated with the thiosulphate after definite intervals, e.g. after 2, 6, 10, 20, 24, 42 hours.

The constant is calculated by means of the equation for a bimolecular reaction.

D. Determination of the Rate of Decomposition of a Diazonium Salt in Aqueous Solution ‡

The decomposition of a diazonium salt, e.g. benzene diazonium chloride, when warmed with water may be represented by the equation

$$C_6H_5{\cdot}N_2Cl + H{\cdot}OH \rightarrow C_6H_5OH + HCl + N_2.$$

* *James* and *Sudborough*, J. C. S. 1907, **91**, 1042.

† See note, p. 389.

‡ *Hantzsch* and *Osswald*, B. 1900, **33**, 2528; *Cain* and *Nicoll*, J. C. S. 1902, **81**, 1412; *Lamplugh*, P. 1906, **22**, 280.

When a dilute aqueous solution is employed, the reaction should be unimolecular.

The concentrations of the solution at time t and at the beginning are best represented in terms of the volume of nitrogen evolved. The total number of ml. of nitrogen evolved will represent the original concentration a, and the number of ml. collected after time t will give the value for x at time t.

The apparatus generally employed is a wide test tube provided with a side tube (1 mm. bore) placed near the top. This side tube is connected with a Hempel gas burette, so that the volume of gas which escapes can be measured after given intervals of time. It is necessary to keep the solution rapidly stirred, as otherwise the nitrogen forms supersaturated solutions. The stirring is accomplished by means of a stirrer worked by a turbine and furnished with a mercury trap so that gas cannot escape through the stirring arrangement. One of the simplest forms of mercury trap is represented in fig. 97. The tube a, which should be slightly wider than the axle s of the stirrer, passes right through the cork, but the wide tube b passes only half-way into the cork and so forms with a a cup into which mercury can be poured. The top part of the stem of the stirrer fits air-tight into the two tubes c and d; c is of the same diameter as a, and the edges of both a and c are made as straight as possible and then rounded off. The wider tube d dips below the surface of the mercury, and thus forms a trap which will not allow gas to escape unless the pressure in the flask reaches a high value. Friction can be diminished by coating the stem of the stirrer with vaseline.

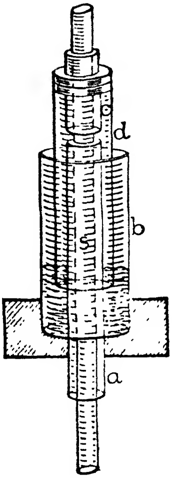


Fig. 97

Experiment 352.—Determine the rate of decomposition of benzene diazonium chloride.

A solution containing 10 g. of the diazonium chloride per litre is prepared by dissolving 6·64 g. (1 mol) of pure aniline in 21·5 ml. (3 mols) of hydrochloric acid (sp. gr. 1·16), cooling with ice, and diazotizing with a solution of 4·93 g. of sodium nitrite in 75 ml. of water (see Exp. 182), and the whole then made up to 1 litre. Sufficient of the solution is introduced

into the tube so as to fill it nearly to the level of the capillary side tube. The tube is fitted with a cork and stirrer and immersed in a thermostat at 20° or 25°, so that the whole of the liquid can be kept at the same temperature. The stirrer is started, and after some seven minutes the side tube is connected with the measuring apparatus and the time noted. This is the zero point from which the subsequent times are reckoned. The first reading may be taken after two hours and subsequent readings every forty-five to sixty minutes. If the mixture is not stirred, the flask should be tapped before each reading is taken, and the level of the water in the two tubes of the Hempel burette are brought to the same level when the reading is taken. The experiment should be conducted in a room the temperature of which remains constant, or the measuring tube should be surrounded by a jacket of cold water, or otherwise the volumes of gas measured will need to be corrected for variations of temperature.

The value of a is obtained by heating the tube by means of hot water, cooling, and repeating the experiment several times until no more gas is evolved, and taking the final reading.

E. Rate of Hydrolysis of an Ester by means of Potassium Hydroxide

The reaction

$$R{\cdot}COOR' + KOH \rightarrow R{\cdot}COOK + R'OH$$

is a typical bimolecular reaction, and its velocity constant may be determined in alcoholic or in aqueous solution if the ester is sufficiently soluble.

If solutions of ester and alkali of the same concentration are employed, equation (3) may be used for calculating the constant, otherwise equation (4).

Experiment 353.—Determine the velocity constant for the hydrolysis of ethyl acetate by potassium hydroxide in aqueous solution at 20°.

Use perfectly clean vessels, and solutions of ester and alkali of 0·025 N. strength. (*N.B.*—The alkali should be free from carbonate and the ester should be quite pure.) The original concentration of the ester solution can be determined from the weight of *pure* ester used, or by hydrolysing a given volume of the ester solution by boiling with an excess of the alkali,

and determining the amount of alkali required for complete hydrolysis by estimating the excess of alkali with standard acid, using phenolphthalein as indicator.

Equal volumes of the two solutions are mixed at the given temperature, and then 30 to 50 ml. of the mixture placed in small bottles in the thermostat. The contents of a bottle are titrated after 5, 10, 20, 30 minutes. The titration is accomplished by adding an excess of standard hydrochloric acid (0·025 N.) and titrating the excess by means of barium hydroxide solution. For a may be substituted the number of ml. of HCl required to neutralize the potash originally present, and for $a - x$ the number of ml. of HCl required to neutralize the potash after time t.

If it is desired to compare the constants for different esters or different alkalis, these should all refer to normal solutions. The value for such can be obtained by taking the constant as calculated above and multiplying by v/N., where v represents the number of ml. of the reaction mixture taken in each experiment, and N. represents the normality of the acid used for titrating.

The velocity constant varies with the alkali employed, with the temperature, and with the ester. This last factor is of considerable interest, and depends both upon the alcohol and the acid from which the ester is derived. The more complex the alkyl radical R′ the less readily is the ester hydrolysed. Similarly, the more complex the acyl group R·CO the less readily is the ester hydrolysed; but another important factor appears to be the strength (activity) of the acid from which the ester is derived.

The following exercises are suggested:

1. Hydrolysis of esters with dilute acids, e.g. methyl acetate in 0·1 N. solutions of hydrochloric and sulphuric acid. This provides a method of comparing the strengths of the two acids.

2. The conversion of acetochloranilide into *p*-chloracetanilide (Exp. 342) by dissolving the chloride in alcohol and making up the solution to 0·1 N. hydrochloric acid. The change is followed by taking aliquot parts of the solution, adding excess of potassium iodide and titrating the liberated iodine with standard thiosulphate.

3. Compare the rates of elimination of hydrogen bromide from the two stereoisomeric dibromo-succinic acids.

Suspend equal weights of the two acids in a little water and add sufficient dilute potassium hydroxide solution (0·25 N.) gradually from a burette until the solution is neutral to phenolphthalein indicator. Add exactly half the volume of alkali and titrate aliquot portions at definite intervals with 0·1 N. acid.

XXXVII. RECOGNITION OF TYPICAL CARBON COMPOUNDS

A. Simple or Complex

The first point to be settled when an organic material is provided for examination is whether it is a single chemical individual or a mixture.

(*a*) If the substance is a liquid, a small amount is heated in order to determine whether it is volatile, and if so it is distilled. If all passes over at a constant temperature, then, in the majority of cases, the conclusion may be drawn that one compound only is present. As a certain number of mixtures of constant boiling-point are known, the possibility of the presence of these should be borne in mind, and the solubilities of the liquid in different solvents should be examined.

If the boiling-point is not constant, then probably the material is a mixture, and in many cases it will be possible to separate the constituents of the mixture by fractional distillation, e.g. a solution of aniline in alcohol or of nitrobenzene in benzene. In certain cases when the liquid of low boiling-point has been removed the residue will solidify and may be purified by crystallization, e.g. a solution of dinitrobenzene in benzene.

If the boiling-points of the different constituents of the mixture are too close to one another for separation by fractional distillation, the components must be separated by chemical methods. Thus a mixture of aniline (b.p. 182°) and nitrobenzene (b.p. 206°) is readily separated by dissolving the aniline in dilute hydrochloric acid, when the oily nitrobenzene would form a separate layer.

If the substance decomposes when heated under atmospheric pressure, an attempt may be made to distil under reduced pressure (fig. 9).

(*b*) If the substance is a solid, its appearance to the naked eye and also under the microscope or lens should be noted. If it is possible under any of these conditions to detect different types of particles, the material is probably a mixture.

The melting-point of the substance may also throw light upon this question. If, when heated, part of the material melts and leaves a number of particles which remain solid even at a much higher temperature, the material is undoubtedly a mixture; or, again, if the actual melting-point covers a wide range of temperature, i.e. it begins to melt at a fixed temperature but is not completely molten until a temperature several degrees higher is attained, the conclusion that we are dealing with a mixture may, as a rule, be drawn. On the other hand, if the substance has a well-defined sharp melting-point, the probability is that it is a single compound.

Further light on this point may be obtained by attempting to fractionally crystallize the substance from a suitable solvent (p. 22). If the melting-points of the different fractions are the same, the conclusion is to be drawn that the substance is a single compound, or that it is a mixture of two closely allied compounds which form mixed crystals (solid solutions). If, on the other hand, the different crystalline fractions have quite different melting-points, then the original material must have been a mixture of two or more compounds.

The action of common chemical reagents, such as dilute hydrochloric acid, dilute sodium carbonate, or sodium hydroxide, may be studied. If part of the substance dissolves readily in the cold solvent, leaving an insoluble residue even in the presence of an excess of the solvent, the conclusion is obvious.

If the material from these preliminary tests appears to be homogeneous, the further examination is carried out as described under C. If there are indications that it is a mixture, the methods of section B must be tried.

B. Separation of Mixture into Components

If the material is a mixture, it is an advantage to separate it into its constituents before a detailed investigation of the chemical nature of these is made. The method of separation to be adopted will, in all probability, have been indicated in the preliminary tests (under section A).

The commoner methods adopted are:

1. Fractional distillation.
2. Fractional crystallization.
3. Fractional solution, when one of the constituents is readily soluble and the other practically insoluble in a given solvent, e.g. cold water would readily extract acetic acid from a mixture of acetic and benzoic acids, and cold benzene benzoic acid from a mixture of the acid and benzanilide.
4. Use of a reagent with which the one compound will react and give a soluble derivative, whereas the other will not, e.g. the separation of an acid from an ester or from an amine, when the ester or amine is insoluble in water, by shaking the mixture with sodium carbonate solution. A good method is to use two liquids, e.g. in the above case ether and sodium carbonate solution. The mixture of acid and ester is dissolved in ether, and the ethereal solution then shaken with dilute sodium hydroxide or sodium carbonate solution. The ether retains the ester, whereas the acid is extracted by the dilute alkali and will be present in the aqueous solution as a sodium salt. The two solutions are separated by means of a tap funnel and each worked up separately. The acid, if insoluble in water, may be precipitated by acidifying the alkaline liquid with a mineral acid, and the ester is obtained when the ethereal solution is dried and the ether removed.
5. A method which can be adopted when one of the constituents of the mixture is readily volatile is to subject the mixture to a process of sublimation (fig. 19). A mixture of naphthalene and acetanilide can be separated quite readily by this method.

Separation of the material into its components having been effected, each individual substance is separately examined according to the scheme outlined in C and D.

C. Examination of some Simple Reactions of a Compound

A considerable amount of useful information with respect to the nature of the chemical compound under examination may often be obtained by performing a few preliminary experiments. Some of the simpler are as follows:

(*a*) Determine the melting-point or boiling-point of the substance.

(*b*) Ignite a small amount of the substance on platinum * and notice if any mineral residue is left. Examine this residue in the ordinary manner for metallic and acid radicals. As a rule it will be a metal, metallic oxide, or carbonate. Occasionally a sulphite, sulphate, or halide.

The formation of a metallic residue indicates the presence of the metallic salts of an acid (sulphonic or carboxylic), or the metallic derivative of a phenol, alcohol, mercaptan, ketone, or aldehyde.

(*c*) Burn a small amount of the substance on a glass rod, or notice how the substance burns in (*b*), also observe odour during burning. All aromatic compounds produce an intensely smoky flame, and, as a rule, give rise to characteristic odours. Very simple aliphatic compounds burn with a non-luminous flame, but an increase in molecular complexity is accompanied by an increase in the luminosity of the flame.

Many carbohydrates when heated char and produce an odour of burning sugar.

(*d*) *Behaviour with water.*—If soluble, test solution and observe if neutral, acid, or alkaline to litmus. A strongly alkaline solution may be due to the presence of a soluble amine, such as trimethylamine, or may be due to the hydrolysis of the sodium or potassium salt of a very feeble acid or acidic compound, e.g. sodium carbonate, potassium cyanide, sodium ethoxide, potassium phenate, &c. If an acid reaction is obtained, it does not necessarily mean that the original compound is a free acid; it may be an acid derivative, e.g. anhydride, chloride, or ester, which has been decomposed by the water, yielding an acid; or it may be the salt of a very feeble base, e.g. aniline hydrochloride. All such salts when dissolved in water are largely hydrolysed (Chap. XII, H, p. 154), and the acid reaction is due to the free mineral or organic acid thus formed.

If the substance is practically insoluble in cold, but dissolves in hot water, and the solution deposits crystals as the solution cools, it is advisable to examine these crystals in order to see whether they are identical with the original compound or not. A melting-point determination, after the crystals are dry, will usually settle this point. The melting-point of a mixture of the crystals and the original compound

* Make sure that lead, mercury, and arsenic compounds are absent.

should also be taken. If succinic anhydride (m.p. 120°) is boiled with water, crystals of succinic acid (m.p. 185°) will separate as the solution cools, if this be sufficiently concentrated; again, if crystals of methyl oxalate are boiled with water, crystals of oxalic acid can be obtained.

(*e*) *With dilute mineral acid, preferably hydrochloric acid.*—If the compound is sparingly soluble in cold water but dissolves readily in cold dilute hydrochloric acid, the presence of an amine or an amino-derivative, e.g. an amino-acid such as *o*-amino-benzoic acid, may be inferred, and experiments may then be made in order to determine the nature of the amine, e.g. primary, secondary, tertiary; aromatic or aliphatic; see Chap. XVIII, E, *et seq.*

If the original substance dissolves readily in cold water and the aqueous solution yields a precipitate on the addition of hydrochloric acid, the substance is undoubtedly the metallic salt of an acid, insoluble in water, probably an aromatic acid. The precipitate can be removed, crystallized, and its physical and chemical characteristics investigated. If the original compound is the salt of a simple aliphatic acid, e.g. ammonium acetate, no change will be observed on the addition of hydrochloric acid. If a silver or lead salt is present, a precipitate of the metallic chloride will be produced on the addition of hydrochloric acid; the majority of silver and lead salts of organic acids, however, are insoluble or only very sparingly soluble in water.

If the compound is insoluble in water and in cold dilute hydrochloric acid, but dissolves in the latter on warming and crystallizes as the solution cools, it is advisable to examine the crystals which separate in order to find out whether they are identical with the original compound or not. α-Naphthylamine is very sparingly soluble in water and also in cold hydrochloric acid, as its hydrochloride is not readily soluble in water. When the base is warmed with excess of dilute hydrochloric acid, a clear solution is obtained and, on cooling, crystals of α-naphthylamine hydrochloride separate, and it will be found that the chemical and physical properties (e.g. melting-point, solubility, &c.) of the crystals are very different from those of the original substance, indicating that the compound must have reacted with the acid, e.g. formed a salt, thus pointing to the basic nature of the compound under investigation.

(*f*) *With a dilute solution of a strong alkali, e.g. potassium hydroxide solution.*—If the compound is insoluble or only sparingly soluble in water, but dissolves readily in dilute caustic potash solution, it must be an acid (carboxylic, sulphonic, or pseudo-acid) or a phenol. The behaviour of the compound towards sodium carbonate solution can be investigated; if insoluble in water but soluble in both sodium carbonate and potassium hydroxide solutions, it is undoubtedly an acid or a strongly acidic phenol, e.g. a nitrophenol; if insoluble in water and in sodium carbonate solution, it is a weakly acidic phenol. Many acids and phenols are fairly readily soluble in water, and it will always be found that an acid, whether soluble or insoluble in water, will completely dissolve in dilute sodium carbonate solution, and that carbon dioxide will be evolved if the carbonate solution is warmed. If the compound is soluble in water, but yields an oil or a precipitate on the addition of alkali, the probability is that the substance is the salt of a base, e.g. of a simple amine or an alkaloid.

If ammonia * is evolved when the substance is heated with potassium hydroxide solution, it may be accepted as an indication of the presence of an ammonium salt, an acid amide, imide, or a nitrile. As a rule the ammonium salts are readily soluble in water (exception, ammonium urate), whereas the acid imides, amides, and nitriles are not, with the exception of those derived from the lower fatty acids. Ammonium salts give up their ammonia, as a rule, more readily than amides or nitriles, e.g. when treated with cold alkali, or, even better, when rubbed with slaked lime and a little water. In order to be sure of recognizing an acid amide, imide or nitrile it is advisable to repeat the experiment, using a hot concentrated solution of the alkali. After the elimination of the ammonia the cooled solution is acidified carefully with hydrochloric acid and the following points noted:

1. The formation of a precipitate of the free acid which can be isolated and examined.

2. The evolution of much carbonic anhydride probably indicates the presence of a derivative of carbonic acid, e.g. urea, carbamic acid, or guanidine.

* Methylamine may easily be confused with ammonia, as it is strongly alkaline and has a similar odour; it can be distinguished from ammonia by its inflammability.

3. A distinct odour without the formation of a precipitate may indicate the presence of one of the lower fatty acids.

The only reliable method of determining whether the compound is the amide, ammonium salt, or nitrile of a given acid is to determine the special acid from which it is derived, and then from an examination of the physical constants of the original compound to determine whether these agree with those of the ammonium salt, amide, or nitrile.

If the substance has a pleasant fruity odour, is insoluble in water, but dissolves gradually when boiled with alkalis (use reflux condenser), then it is probably an ester. The hydrolysis can be completed and the liquid examined for both alcohol and acid (cf. Chap. XIII, F).

Both chloral and bromal and their hydrates are decomposed by alkalis, and colourless oils with pleasant sweet odours are formed; these oils are chloroform and bromoform respectively, and their boiling-points may be determined. The alkaline solution can also be tested for a formate:

$$CCl_3{\cdot}CHO + KOH = CHCl_3 + H{\cdot}COOK.$$

It is necessary to bear in mind that a given compound may give the reactions characteristic of two or more different types of compounds. This is due to the fact that the compound in question contains two or more characteristic atomic groupings or radicals in the molecule. Thus succinamic acid, $NH_2{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}CO{\cdot}OH$, as a free acid, dissolves readily in sodium carbonate or potassium hydroxide solution, although only sparingly soluble in water; but it also possesses the properties of an acid amide, and evolves ammonia when boiled with potash. The fact that it yields succinic acid when hydrolysed indicates that it must be a derivative of this acid; its solubility in sodium carbonate solution shows that it must be an acid; and the evolution of ammonia indicates that it must be an ammonium salt, acid amide, or nitrile. An examination of its solubility in water, of its melting-point, and of certain derivatives will decide which of these it is.

Methyl salicylate, $OH{\cdot}C_6H_4{\cdot}CO_2Me$, is both a phenol and an ester. On treatment with cold dilute potassium hydroxide a precipitate of $OK{\cdot}C_6H_4{\cdot}CO_2Me$ is formed. This dissolves immediately on warming, and addition of a mineral acid regenerates the oil. If, however, the alkaline solution is boiled,

the ester is hydrolysed and acidification yields a precipitate of free salicylic acid.

Certain compounds when boiled for some time with concentrated potash are decomposed, and yield oils or solids of low melting-point which have odours characteristic of aromatic amines. Such behaviour points to the presence of an acyl derivative of an arylamine (an anilide, toluidide, &c.), and the compound should be completely hydrolysed with concentrated potash, or concentrated hydrochloric acid, and the product examined for the organic acid and for the amine.

(*g*) A substance should be examined for reducing properties by testing with Fehling's solution (Chap. XXXIV) and with ammoniacal silver nitrate (Exp. 206). Strong reducing properties are characteristic of practically all aldehydes, including the commoner monosaccharides such as glucose and fructose (a hydroxy-ketone), and some disaccharides such as maltose. Formic acid and its salts are also strongly reducing compounds, and also a few simple ketones, alcohols, and polyhydroxyphenols. Certain complex compounds do not reduce directly, but have strong reducing properties after hydrolysis with mineral acids. To this category belong disaccharides of the type of cane sugar, polysaccharides such as starch, dextrin, and practically all glucosides (S.B. Chap. XIV, and this chapter, p. 427).

D. Determination of Elements Present

The preliminary tests given under C will have indicated the presence of certain elements in the compound under examination. Other elements not detected in this preliminary examination should be tested for as indicated below. The possible presence of metals which give volatile compounds (Hg, Sb, As) should be considered.

For C and H, see p. 39.

For N, the sodium test (p. 40) or *Castellana's test* (p. 41) is usually employed.

For halogens, the copper oxide wire, sodium, or lime test (p. 41).

For sulphur, the nitro-prusside test (p. 42).

E. More Important Groups of Compounds

Preliminary investigations thus outlined, including the determination of the elements present and the solubilities of the compound in the commoner organic solvents, e.g. alcohol, ether, benzene, will, as a rule, give some clear indication of the probable nature of the substance, and a more detailed investigation may be made as described under the following headings:

Hydrocarbons, Tables I and II.
Halogen derivatives, Table III.
Alcohols, Table IV.
Phenols, p. 202 and Table V.
Nitro-compounds, p. 185 and Table VI.
Acids, p. 154 and Tables VII, VIII, IX and X.
Aldehydes, p. 260 and Table XI.
Ketones, p. 265 and Table XII.
Amines, p. 226 and Tables XIII, XIV and XV.
Alkaloids, p. 421.
Sulphonic acids, p. 195.
Acyl derivatives, pp. 203, 230.
Compounds with double functions, pp. 421, 422 and Tables XVI, XVII, XVIII.
Carbohydrates, p. 424, 425 and Table XIX.

The two most difficult classes of compounds to characterize are probably hydrocarbons and ethers (alcoholic or phenolic). As a rule the other groups of compounds must be eliminated. The ethers react when warmed with PCl_5, whereas the hydrocarbons do not. If other compounds have been shown to be absent and it is thought that a benzene hydrocarbon is present, the specific hydrocarbon can be identified by: (*a*) physical constants of the compound; (*b*) oxidation to an aromatic acid usually by chromic anhydride, and recognition of this acid; (*c*) preparation of a solid nitro- or other substituted derivative; (*d*) in certain cases, e.g. naphthalene or anthracene, the crystalline picrates can be prepared. Naphthalene picrate forms golden-yellow crystals, m.p. 149°; anthracene picrate, red crystals, m.p. 138°; phenanthrene picrate, golden-yellow crystals, m.p. 145°.

If an ether is thought to be present it can be hydrolysed (Chap. XVII, F) and the alcohol or phenol recognized.

For reference purposes the physical constants of the commoner members of the more important groups are given in the

following tables, together with the melting-point or boiling-point of characteristic derivatives.

These lists are by no means exhaustive, and compounds not mentioned in these lists can be found by reference to the following works:

Beilstein's Handbuch der organische Chemie; *Heilbron's* Dictionary of Organic Compounds; or the Tables in *Hickinbottom's* Reactions of Organic Compounds, or *Hopkin and Williams'* Organic Reagents for Organic Analysis.

TABLE I.—HYDROCARBONS, ALIPHATIC

A. SATURATED. NORMAL	B.P.	B. OLEFINIC	B.P.
CH_4 to C_4H_{10} are gases		C_2H_4 to C_4H_8 are gases ..	
Pentane, C_5H_{12} ..	36	Isoamylene, C_5H_{10}	39
Hexane, C_6H_{14}	69	*n*-Hexylene, C_6H_{12}	68
Heptane, C_7H_{16} ..	98	*n*-Heptylene, C_7H_{14}	95
Octane, C_8H_{18}	126	*n*-Octylene, C_8H_{16}	123
Nonane, C_9H_{20}	150	*n*-Nonylene, C_9H_{18}	153
Decane, $C_{10}H_{22}$ ..	173	**C. DI-ENES**	**B.P.**
Undecane, $C_{11}H_{24}$ ..	195	Butadiene, C_4H_6	1
Dodecane, $C_{12}H_{26}$ ..	214	Isoprene, C_5H_8	34
		2:3-Dimethylbuta-1:3-diene, C_6H_{10}	70

TABLE II.—HYDROCARBONS, CYCLIC

A. MONOCYCLIC	B.P.
Benzene, C_6H_6 ..	80
Toluene, C_7H_8 ..	110
Xylene *o*, $C_6H_4(CH_3)_2$	142
m, ,,	139
p, ,,	138
Ethylbenzene, $C_6H_5{\cdot}C_2H_5$ ..	136
Hemimellithene, $C_6H_3(CH_3)_3$ 1:2:3	175
Pseudocumene, $C_6H_3(CH_3)_3$ 1:2:4	170
Mesitylene, $C_6H_3(CH_3)_3$ 1:3:5	165
Cumene, $C_6H_5{\cdot}C_3H_7$	153
Durene, $C_6H_2(CH_3)_4$ 1:2:4:5	192
Metacymene, $C_6H_4(CH_3){\cdot}C_3H_7$ 1:3	175
Cymene, $C_6H_4(CH_3){\cdot}C_3H_7$ 1:4	175
Styrene, $C_6H_5CH{:}CH_2$	140
Phenylacetylene, $C_6H_5C{:}CH$ ..	142

B. POLYCYCLIC	M.P.	B.P.	T.N.B. COMP.
Diphenyl, $C_6H_5{\cdot}C_6H_5$	71	254	—
Diphenylmethane, $(C_6H_5)_2{\cdot}CH_2$ ..	26	262	—
Triphenylmethane, $(C_6H_5)_3{\cdot}CH$ ..	93	—	—
Dibenzyl, $(C_6H_5{\cdot}CH_2)_2$	52	—	102
1:1-Diphenylethane, $(C_6H_5)_2{\cdot}CH{\cdot}CH_3$ ..		286	—
Stilbene, $C_6H_5CH=CH{\cdot}C_6H_5$	125	—	120
Tolane, $C_6H_5C\equiv C{\cdot}C_6H_5$ ..	60	—	96

C. CONDENSED NUCLEI	M.P.	PICRATE	T.N.B. COMP.
Naphthalene, $C_{10}H_8$	81	149	152
Anthracene, $C_{14}H_{10}$	216	138	164
Phenanthrene, $C_{14}H_{10}$	100	143	164
Pyrene, $C_{16}H_{10}$ ..	149	229	245
Chrysene, $C_{18}H_{12}$ ..	250	273	186
Retene, $C_{18}H_{18}$ ..	98	123	139

TABLE III.—HALOGEN DERIVATIVES (Boiling-points of)

A. Aliphatic *	Chloride	Bromide	Iodide	B. Aromatic	Chloride	Bromide	Iodide
Methyl, CH_3X	−23·7	4·5	45	Phenyl, C_6H_5X	132	157	188
Ethyl, C_2H_5X	12·2	38·4	72·3	Phenylene *o*, $C_6H_4X_2$ ..	179	224	286 (27)*
n-Propyl, C_3H_7X ..	46·5	71	102	*m*, ,, ..	172	220	285 (40)*
iso-Propyl, C_3H_7X ..	36·5	60	89	*p*, ,, ..	173 (56)*	219 (87)*	285 (129)*
n-Butyl (primary), C_4H_9X	78	101	130	Tolyl *o*, $CH_3{\cdot}C_6H_4{\cdot}X$ ..	159	181	211
iso-Amyl	100	120	147	*m*, ,, ..	162	184	204
Allyl, C_3H_5X	45	70	101	*p*, ,, ..	162	185	211 (35)*
CHX_3	61	151	119*	Benzyl, $C_6H_5CH_2X$ ..	175	198	— (24)*
CX_4	76	92*	—	Benzal, $C_6H_5{\cdot}CHX_2$ ..	205	—	—
Methylene, CH_2X_2 ..	42	97	180	$C_6H_5{\cdot}CX_3$ ..	214	—	—
Ethylene, $C_2H_4X_2$ ..	58	110	178	C_6X_6	(229)*	—	—

* Melting-points.

TABLE IV.—ALCOHOLS AND RELATED COMPOUNDS

Alcohol	Ethers					Esters				
	M.P.	B.P.	Methyl B.P.	Ethyl B.P.	2:4-Dinitrophenyl M.P.	Acetate M.P.	Acetate B.P.	Benzoate M.P.	Benzoate B.P.	3:5-Dinitrobenzoate M.P.
Methyl	—	67	*g**	*g*	94	—	57	—	199	109
Ethyl	—	78	*g*	35	87	—	77	—	212	94
n-Propyl	—	97	39	64	—	—	101	—	229	75
iso-Propyl	—	82	32	54	—	—	91	—	219	122
n-Butyl	—	117	70	92	—	—	125	—	247	62
iso-Butyl	—	108	59	80	—	—	116	—	234	88
sec-Butyl	—	100	—	—	—	—	112	—	234	76
tert-Butyl	—	83	54	70	—	—	95	—	—	142
iso-Amyl	—	131	91	112	—	—	140	—	261	62
active-*l*-Amyl	—	128	88	109	—	—	—	—	—	70
Allyl	—	97	-	—	46	—	103	—	230	50
Cetyl	48	—	—	—	—	22	—	30	—	66
Ethylene glycol ..	—	198	82	123†	—	—	187†	73†	—	—
Glycerol	—	290	—	185‡	—	—	258‡	73‡	—	—
Mannitol	166	—	—	—	—	119§	—	—	125§	—
cyclo-Hexanol ..	-	160	135	150	—	—	176	—	—	113
Benzyl	—	206	168	185	149	—	216	76	345	113
β-Phenylethyl ..	—	220	185	190	—	—	232	—	—	108
Cinnamyl	33	250	—	—	—	—	—	—	—	121
Diphenylcarbinol ..	68	298	271	288	—	41	—	—	—	141
Triphenylcarbinol ..	163	—	—	—	—	—	—	—	—	—
l-Menthol	44	21[illegible]	—	—	—	—	228	54	—	153
d-Borneol	204	212	—	—	—	29	—	25	—	154

* *g* = gaseous. † di- derivs. ‡ tri- derivs. § hexa- derivs.

TABLE V.—PHENOLS AND RELATED COMPOUNDS

			Ethers		Esters			
	B.P.	M.P.	Methyl B.P.	2:4-Dinitrophenyl M.P.	B.P.	Acetate M.P.	Benzoate M.P.	3:5-Dinitrobenzoate M.P.
Phenol	181	43	152	69	195	—	69	146
o-Cresol	191	30	171	90	208	—	—	138
m- ,, ...	202	—	177	74	212	—	54	165
p- ,, ...	200	36	175	93	208	—	—	187
Carvacrol	237	—	217	—	246	—	—	76
Thymol	232	51	217	—	244	—	32	130
Pseudocuminol	230	70	—	—	—	—	63	—
Eugenol	254	—	—	—	—	31	69	131
iso-Eugenol	261	—	—	—	—	79	103	158
Catechol	—	105	205	—	—	64	84	—
Resorcinol	—	110	214	194	273	—	117	—
Quinol	—	170	205	—	—	124	199	—
Orcinol	287	108	244	—	-	25	88	—
Pyrogallol	—	133	235	—	—	161	89	—
Phloroglucinol	—	218	—	—	—	105	173	—
Guaiacol*	—	32	205	—	235	—	57	141
α-Naphthol	280	94	258	128	—	46	56	217
β- ,, ...	285	123	72†	95	—	70	106	210

* Catechol monomethyl ether.   † M.P.

TABLE V (*contd.*).—HALOGENATED AND NITRO- PHENOLS

	B.P.	M.P.	Acetate M.P.	Benzoate M.P.
o-Chlorophenol ..	175	7	—	—
m- „ ..	214	29	—	71
p- „ ..	217	41	—	86
o-Bromophenol ..	194	—	—	—
m- „ ..	236	33	—	86
p- „ ..	236	64	21	102
p-Iodophenol ..	—	92	32	119
5-Chloro-*o*-cresol ..	—	48	—	71
3-Bromo-*p*-cresol ..	214	—	—	—
2:4-Di-iodo-phenol	—	72	72	—
3:5-Dibromo-*o*-cresol	—	56	—	—
3:5-Dibromo-*p*-cresol	—	49	—	—
2:4:6-Trichlorophenol	—	67	—	70
2:4:6-Tribromophenol	—	96	82	81

	M.P.	Acetate M.P.	Benzoate M.P.
3:5:6-Tribromo-*o*-cresol	79	—	—
2:3:5-Tribromo- „	96	72	—
2:4:6-Tribromo-resorcinol	111	—	—
Tetrachloroquinol ..	232	—	—
Tetrabromoquinol ..	244	—	—
o-Nitrophenol	44	39	59
m- „	96	—	95
p- „	114	82	142
2:4-Dinitrophenol ..	113	72	132
2:4:6-Trinitrophenol (Picric acid) ..	122	—	163
5-Nitro-*o*-cresol ..	118	—	128
4-Nitro-*m*-cresol ..	56	—	—
3-Nitro-*p*-cresol ..	34	—	102
2:4:6-Trinitroresorcinol (Styphnic acid) ..	175	—	—

TABLE VI.—NITRO-COMPOUNDS

A. Aliphatic	B.P.	Isomeric nitrites
Nitromethane	100	Gas
Nitroethane	113	18
Isoamyl	—	96
B. Aromatic	**M.P.**	**B.P.**
Nitrobenzene	5·3	208
o-Di- „	117	319
m-Di- „	90	302
p-Di- „	172	299
s-Tri- „	122	decn.
as-Tri- „	57·5	decn.
o-Nitrotoluene	—	218
m- „	16	234
p- „	51	234
2:4-Dinitrotoluene	70	decn.
2:6- „	66	decn.
s-Trinitrotoluene	81	
4-Nitroxylene 1:3:4	2	246
Nitromesitylene	44	255

TABLE VII.—ALIPHATIC MONOBASIC ACIDS

The majority are soluble in water, except the higher acids

Acid	Formula	M.P.	B.P.	Ethyl Ester B.P.	Methyl Ester M.P.	Methyl Ester B.P.	Anhydride M.P.	Anhydride B.P.	Amide M.P.	Amide B.P.	Anilide M.P.
Formic ..	$H \cdot CO_2H$	—	101	55	—	32·5	—	—	—	200–212	46
Acetic	$CH_3 \cdot CO_2H$	—	118	78	—	57·5	—	136·5	82	—	115
Propionic ..	$CH_3 \cdot CH_2 \cdot CO_2H$	—	141	99	—	80	—	168·6	79	—	105
n-Butyric ..	$CH_3 \cdot (CH_2)_2 \cdot CO_2H$	—	162	121	—	102	—	192	115	—	92
iso-Butyric ..	$(CH_3)_2CH \cdot CO_2H$	—	154	110	—	92	—	182	128	—	102·5
iso-Valernic ..	$(CH_3)_2CH \cdot CH_2 \cdot CO_2H$	—	174	134	—	117	—	215	128	—	115
Myristic ..	$CH_3 \cdot (CH_2)_{12} \cdot CO_2H$	54	—	295	—	—	51	—	102	—	84
Palmitic ..	$CH_3(CH_2)_{14} \cdot CO_2H$	62	—	*	28	—	64	—	104	—	90·5
Stearic ..	$CH_3(CH_2)_{16} \cdot CO_2H$	69	—	*	38	—	—	—	109	—	—
Chloracetic ..	$CH_2Cl \cdot CO_2H$	63	185	145	—	130	—	168 (dec.)	119	—	134·5
Dichloracetic ..	$CHCl_2 \cdot CO_2H$	—	190	158	—	143	—	214 (dec.)	98	—	117
Trichloracetic ..	$CCl_3 \cdot CO_2H$	55	195	167	—	152	—	224	141	—	82
Bromacetic ..	$CH_2Br \cdot CO_2H$	50	208	159	—	144	—	245	91	—	131
Tribromacetic ..	$CBr_3 \cdot CO_2H$	135	(dec.)	225	—	—	—	—	121	—	—
Unsaturated—											
Crotonic ..	$CH_3 \cdot CH{:}CH \cdot CO_2H$	72	182	142	—	121	—	—	149	—	118
Oleic	$C_{18}H_{34}O_2$	14	—	*	—	—	—	—	75	—	—
Elaidic ..	,,	51	—	*	—	—	50	—	93–94	—	—
Erucic	$C_{22}H_{42}O_2$	34	—	*	—	—	—	—	84	—	55

* Decomposes.

TABLE VIII.—AROMATIC MONOBASIC ACIDS

Acid	Formula	M.P.	Ethyl Ester		Methyl Ester		Chloride		Anhydride M.P.	Amide M.P.	Anilide M.P.
			M.P.	B.P.	M.P.	B.P.	M.P.	B.P.			
Benzoic	$C_6H_5 \cdot CO_2H$	121	—	211	—	195	—	198	42	128	163
o-Toluic	$CH_3 \cdot C_6H_4 \cdot CO_2H$	105	—	220	—	—	—	211	36–38	139	125
p- ,, ...	,,	179	—	228	32	217	—	214	—	158	145
Phenyl-acetic ..	$C_6H_5 \cdot CH_2 \cdot CO_2H$	76	—	226	—	220	—	102·5 (17 mm.)	72·5	155	117
o-Chlor-benzoic ..	$C_6H_4Cl \cdot CO_2H$	138	—	243	—	230	—	235	—	139	114
m- ,, ..	,,	153	—	245	21	114	—	225	—	133	—
p- ,, ..	,,	234	—	—	42	—	—	220	—	170	194
o-Brom-benzoic ..	$C_6H_4Br \cdot CO_2H$	150	—	254	—	246	—	241	—	156	142
m- ,, ..	,,	155	—	259	32	122	—	239	—	151	137
p- ,, ..	,,	251	—	262	74	—	42	245	213	186	197
o-Nitro-benzoic ..	$NO_2 \cdot C_6H_4 \cdot CO_2H$	148	30	—	—	—	—	—	135	176	—
m- ,, ..	,,	141	47	298	70	279	35	184 (50 mm.)	—	143	154
p- ,, ..	,,	240	57	—	96	—	75	202 (105 mm.)	—	198	204
Hydrocinnamic ..	$C_6H_5 \cdot (CH_2)_2 \cdot CO_2H$	48·5	—	249	—	239	—	119 (13 mm.)	—	82	92
Unsaturated—											
Cinnamic ..	$C_6H_5CH{:}CH \cdot CO_2H$	133	12	271	36	260	36	154 (25 mm.)	135	147	151
Atropic	$CH_2{:}C(C_6H_5) \cdot CO_2H$	106	—	—	—	—	—	—	—	—	—
Phenyl-propiolic	$C_6H_5C{\vdots}C \cdot CO_2H$	136	—	—	—	—	—	130 (25 mm.)	—	100	126

TABLE IX.—DIBASIC ACIDS, ALIPHATIC AND AROMATIC

Acid	Formula	M.P.	Normal Methyl Ester		Normal Ethyl Ester		Anhydride M.P.	Amide M.P.	Imide M.P.	Anilide M.P.
			M.P.	B.P.	M.P.	B.P.				
Aliphatic—										
Carbonic ..	$CO(OH)_2$	—	—	91	—	126	—	132	—	235
Oxalic ..	$CO_2H{\cdot}CO_2H$	98	54	163	—	186	—	(dec.)	—	245
Malonic ..	$CO_2H{\cdot}CH_2{\cdot}CO_2H$	132	—	182	—	198	—	170	—	224
Succinic ..	$CO_2H{\cdot}(CH_2)_2{\cdot}CO_2H$	185	18	195	—	217	119	242	126	227
Glutaric ..	$CO_2H{\cdot}(CH_2)_3{\cdot}CO_2H$	97·5	—	—	—	236	56	176 (dec.)	60	224
Malic	$CO_2H{\cdot}CH_2{\cdot}CH(OH){\cdot}CO_2H$	100	—	122 (10 mm.)	—	128 (10 mm.)	—	—	—	197
Tartaric ..	$CO_2H{\cdot}(CH{\cdot}OH)_2{\cdot}CO_2H$	168	48	280	—	280	—	—	—	263
Aromatic—										
Phthalic ..	$C_6H_4(CO_2H)_2$ (1:2)	184	—	282	—	295	128	—	233	231 (dec.)
Iso-phthalic ..	,, (1:3)	300	64	(dec.)	—	285	—	265	—	250
Tere-phthalic..	,, (1:4)	—	140	—	44	—	—	—	—	—

Recognition of Acids.

The majority of organic acids are sparingly soluble in water and can readily be isolated and purified by methods already indicated, their equivalents and melting-points determined and derivatives prepared (cf. Tables VII–IX).

For acids which are readily soluble in water and hence difficult to isolate quickly in pure form, precipitation methods may be employed for their identification. The aqueous solution of the acid is carefully neutralized with sodium hydroxide, and portions tested with bench solutions of (*a*) $CaCl_2$, (*b*) $Ba(NO_3)_2$, (*c*) $FeCl_3$, (*d*) $AgNO_3$. The formation of precipitates for a number of common acids is given in Table X.

TABLE X

Acid	Ca	Ba	Fe'''	Ag
Formic ..	No pp.	No pp.	Red sol. pp. on boiling	White pp. (r)†
Acetic ..	,,	,,	,,	No pp.
n-Butyric	No pp. in cold*	,,	Red pp.	White pp.
Lactic ..	No pp.	No pp.	No pp. or coloration	No pp.
Oxalic ..	White pp.	White pp.	,,	White pp.
Malonic ..	No pp.	,,	,,	,,
Succinic ..	White pp.	,,	Pale red pp.	,,
Malic ..	No pp.	No pp.	No pp. or col.	,,
Tartaric ..	White pp.	White pp.	,,	,,
Citric ..	No pp. in cold, pp. on boiling	,,	,,	White pp. (r)† on boiling
Hydrocyanic	No pp.	No pp.	,,	White pp.
Hydroferro-cyanic	No pp.	,,	Prussian blue pp.	,,
Hydroferri-cyanic	,,	,,	No pp.‡	,,
Thiocyanic	,,	,,	Deep red col.	,,

* Ca *n*-Butyrate is more sol. in cold than in hot water. A precipitate may therefore appear on warming.

† Precipitates of Ag salts should be dissolved by careful addition of ammonia and warmed to detect reduction (r).

‡ Deep blue pp. with a ferrous salt.

TABLE XI.—ALDEHYDES AND THEIR DERIVATIVES

	Formula	M.P.	B.P.	Melting-points of				
				Semi-carbazone	Phenyl-hydrazone	2:4-Dinitro-phenyl-hydrazone	Oxime α	Oxime β
Aliphatic—								
Formaldehyde*	HCHO	—	−21	169(d)	—	168	—	—
Paraformaldehyde [a] ..	$(CH_2O)_3$	121–3	—	—	—	—	—	—
Metaformaldehyde [b] ..	$(CH_2O)n_3$	64	—	—	—	—	—	—
Acetaldehyde	$CH_3\cdot CHO$	—	21	163	63	168	47	—
Paraldehyde	$(C_2H_4O)_3$	—	124	—	—	—	—	—
Metaldehyde†	(C_2H_4O)	112(s)	—	—	—	—	—	—
Propaldehyde	C_2H_5CHO	—	49	89	—	155	—	—
Acrolein	$CH_2{:}CH\cdot CHO$	—	52	171	—	165	—	—
Crotonaldehyde ..	$CH_3\cdot CH{:}CH\cdot CHO$	—	104	201	56	190	119	—
Aldol	$CH_3\cdot CHOH\cdot CH_2\cdot CHO$	—	77 (16 mm.)	194	—	—	—	—
Glyoxal	$CHO\cdot CHO$	—	—	—	177‡	327‡	—	—
Methylglyoxal	$CH_3CO\cdot CHO$	—	—	—	145‡	—	—	—

Aromatic—								
Benzaldehyde	$C_6H_5 \cdot CHO$	—	179	214	156	235	35	125
o-Tolylaldehyde ..	$C_6H_4(CHO)CH_3(1:2)$	—	200	224	—	194	49	—
m- ,, ...	,, (1:3)	—	199	216	91	—	60	—
p- ,, ...	,, (1:4)	—	204	234	113	234	80	—
p-Cuminaldehyde ..	$C_6H_4(CHO)C_3H_7(1:4)$	—	235	210	129	243	58	—
o-Nitrobenzaldehyde ..	$C_6H_4(CHO)NO_2(1:2)$	44	—	256	153	—	103	154
m- ,, ...	,, (1:3)	58	—	246	120	—	121	—
p- ,, ...	,, (1:4)	106	—	220	155	320	182	133
Salicylicaldehyde ..	$C_6H_4(CHO)OH(1:2)$	—	197	225	143	248	57	—
p-Hydroxy-benzaldehyde	,, (1:4)	115	—	224	177	157	72	—
Protocatechnic aldehyde	$C_6H_3(CHO)(OH)_2(1:3:4)$	153	—	—	175	—	149	—
Anisic aldehyde ..	$C_6H_4(CHO)(OCH_3)(1:4)$	—	248	210	121	253	—	—
Vanillin	$C_6H_3(CHO)(OCH_3)OH(1:3:4)$	81	285	229	105	271	117	—
Piperonal	$C_6H_3(CHO)(CH_2O_2)(1:3:4)$	37	263	233	103	266	110	—
Phenylacetic aldehyde ..	$C_6H_5CH_2 \cdot CHO$	—	194	156	58	121	103	—
Hydrocinnamic aldehyde	$C_6H_5CH_2 \cdot CH_2 \cdot CHO$	—	224	131	—	—	94	—
Cinnamic aldehyde ..	$C_6H_5CH{:}CH \cdot CHO$	—	246	215	168	255	138	—
Furfural	$C_4H_3O \cdot CHO$	—	161	203	98	229	—	—
Citral (geranial) ..	$C_9H_{15}CHO$	—	226	164	—	116	—	—

• "Formalin" is 40 per cent solution. [a] Solid: sublimes under 100°. [b] Trioxymethylene. † "Meta". ‡ Osazone.

TABLE XII.—KETONES, QUINONES AND THEIR DERIVATIVES

	Formula	M.P.	B.P.	Melting-points of: Semi-carbazone	Phenyl-hydrazone	2:4-Dinitro-phenyl-hydrazone	Oximes: α	β	
Aliphatic—									
Acetone	$CH_3\cdot CO\cdot CH_3$	—	56	187	42	128	59	—	—
Methylethyl ketone ..	$CH_3\cdot CO\cdot C_2H_5$	—	78	135	—	115	—	—	—
Methyl-*n*-propyl ketone	$CH_3\cdot CO\cdot C_3H_7(n)$	—	102	108	—	143	—	—	—
Methyl-*iso*-propyl ,, ..	,, (i)	—	94	112	—	117	—	—	—
Diethyl ketone	$C_2H_5\cdot CO\cdot C_2H_5$	—	101	139	—	156	—	—	—
Mesityl oxide	$CH_3\cdot CO\cdot CH{:}C(CH_3)_2$	—	130	156	—	203	—	—	—
Diacetone alcohol ..	$(CH_3)_2\cdot C(OH)\cdot CH_2\cdot CO\cdot CH_3$	—	164	—	—	202	56	—	—
Aromatic—									
Acetophenone	$C_6H_5\cdot CO\cdot CH_3$	20·5	202	167	105	249	59	—	—
Benzophenone	$C_6H_5\cdot CO\cdot C_6H_5$	48	306	164	137	238	140	—	—
Benzalacetone	$CH_3\cdot CO\cdot CH{:}CH\cdot C_6H_5$	42	260	186	156	227	115	—	—
Dibenzalacetone ..	$C_6H_5CH{=}CH\cdot CO\cdot CH{=}CH\cdot C_6H_5$	112	—	—	—	178	—	—	—
Benzoin	$C_6H_5CH(OH)\cdot CO\cdot C_6H_5$	137	320	206(d)	156	245	151	—	—

Cyclic—										
Cyclohexanone	$C_6H_{10}O$	—	155	166	77	162	88	—	—
2-Methyl-*cyclo*-hexanone	$C_7H_{12}O$	—	163	196	—	136	43	—	—
3- ,, ,, ,,	,,	—	168	190	94	155	—	—	—
4- ,, ,, ,,	,,	—	169	197	—	—	39	—	—
Camphor (*d*)	$C_{10}H_{16}O$	179	204	236	233	177	120	—	—
Menthone (*l*)	$C_{10}H_{18}O$	—	208	184	53	146	59	—	—
Carvone (*d*)	$C_{10}H_{14}O$	62	230	162	110	190	72	—	—
β-Ionone	$C_{13}H_{20}O$	—	150 (24 mm.)	148	—	—	—	—	—
Diketones—										
Acetylacetone	$CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}CH_3$	—	137	—	—	209*	149*	—	—
Benzoylacetone	$C_6H_5{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}CH_3$	61	264	—	—	—	—	—	—
Benzil	$C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5$	95	346	—	225*	189*	237*	209*	163*
Quinones—										
Benzoquinone	$C_6H_4O_2$	116	—	—	—	—	240(d)*	—	—
Camphorquinone ..	$C_{10}H_{14}O_2$	198	—	—	—	—	—	—	—
Anthraquinone	$C_{14}H_8O_2$	285	—	—	—	—	—	—	—
Phenanthraquinone ..	,,	200	—	—	—	—	—	—	—

* Denotes di- derivatives.

TABLE V (*contd.*).—HALOGENATED AND NITRO- PHENOLS

	B.P.	M.P.	Acetate M.P.	Benzoate M.P.		M.P.	Acetate M.P.	Benzoate M.P.
o-Chlorophenol ..	175	7	—	—	3:5:6-Tribromo-*o*-cresol	79	—	—
m- ,, ..	214	29	—	71	2:3:5-Tribromo- ,,	96	72	—
p- ,, ..	217	41	—	86	2:4:6-Tribromo-resorcinol	111	—	—
o-Bromophenol ..	194	—	—	—	Tetrachloroquinol ..	232	—	—
m- ,, ..	236	33	—	86	Tetrabromoquinol ..	244	—	—
p- ,, ..	236	64	21	102	*o*-Nitrophenol	44	39	59
p-Iodophenol ..	—	92	32	119	*m*- ,, ...	96	—	95
5-Chloro-*o*-cresol ..	—	48	—	71	*p*- ,, ...	114	82	142
3-Bromo-*p*-cresol ..	214	—	—	—	2:4-Dinitrophenol ..	113	72	132
2:4-Di-iodo-phenol	—	72	72	—	2:4:6-Trinitrophenol (Picric acid) ..	122	—	163
3:5-Dibromo-*o*-cresol	—	56	—	—	5-Nitro-*o*-cresol ..	118	—	128
3:5-Dibromo-*p*-cresol	—	49	—	—	4-Nitro-*m*-cresol ..	56	—	—
2:4:6-Trichlorophenol	—	67	—	70	3-Nitro-*p*-cresol ..	34	—	102
2:4:6-Tribromophenol	—	96	82	81	2:4:6-Trinitroresorcinol (Styphnic acid) ..	175	—	—

TABLE VI.—NITRO-COMPOUNDS

A. ALIPHATIC	B.P.	Isomeric nitrites
Nitromethane	100	Gas
Nitroethane	113	18
Isoamyl	—	96
B. AROMATIC	**M.P.**	**B.P.**
Nitrobenzene	5·3	208
o-Di- ,, ...	117	319
m-Di- ,, ...	90	302
p-Di- ,, ...	172	299
s-Tri- ,, ...	122	decn.
as-Tri- ,, ...	57·5	decn.
o-Nitrotoluene	—	218
m- ,, ...	16	234
p- ,, ...	51	234
2:4-Dinitrotoluene	70	decn.
2:6- ,, ...	66	decn.
s-Trinitrotoluene	81	
4-Nitroxylene 1:3:4	2	246
Nitromesitylene	44	255

TABLE VII.—ALIPHATIC MONOBASIC ACIDS

The majority are soluble in water, except the higher acids

Acid	Formula	M.P.	B.P.	Ethyl Ester B.P.	Methyl Ester M.P.	Methyl Ester B.P.	Anhydride M.P.	Anhydride B.P.	Amide M.P.	Amide B.P.	Anilide M.P.
Formic ..	$H\cdot CO_2H$	—	101	55	—	32·5	—	—	—	200–212	46
Acetic	$CH_3\cdot CO_2H$	—	118	78	—	57·5	—	136·5	82	—	115
Propionic ..	$CH_3\cdot CH_2\cdot CO_2H$	—	141	99	—	80	—	168·6	79	—	105
n-Butyric ..	$CH_3\cdot (CH_2)_2\cdot CO_2H$	—	162	121	—	102	—	192	115	—	92
iso-Butyric ..	$(CH_3)_2CH\cdot CO_2H$	—	154	110	—	92	—	182	128	—	102·5
iso-Valeric ..	$(CH_3)_2CH\cdot CH_2\cdot CO_2H$	—	174	134	—	117	—	215	128	—	115
Myristic ..	$CH_3\cdot (CH_2)_{12}\cdot CO_2H$	54	—	295	—	—	51	—	102	—	84
Palmitic ..	$CH_3(CH_2)_{14}\cdot CO_2H$	62	—	*	28	—	64	—	104	—	90·5
Stearic ..	$CH_3(CH_2)_{16}\cdot CO_2H$	69	—	*	38	—	—	—	109	—	—
Chloracetic ..	$CH_2Cl\cdot CO_2H$	63	185	145	—	130	—	168 (dec.)	119	—	134·5
Dichloracetic ..	$CHCl_2\cdot CO_2H$	—	190	158	—	143	—	214 (dec.)	98	—	117
Trichloracetic ..	$CCl_3\cdot CO_2H$	55	195	167	—	152	—	224	141	—	82
Bromacetic ..	$CH_2Br\cdot CO_2H$	50	208 (dec.)	159	—	144	—	245	91	—	131
Tribromacetic ..	$CBr_3\cdot CO_2H$	135		225	—	—	—	—	121	—	—
Unsaturated—											
Crotonic ..	$CH_3\cdot CH{:}CH\cdot CO_2H$	72	182	142	—	121	—	—	149	—	118
Oleic	$C_{18}H_{34}O_2$	14	—	*	—	—	—	—	75	—	—
Elaidic ..	"	51	—	*	—	—	50	—	93–94	—	—
Erucic	$C_{22}H_{42}O_2$	34	—	*	—	—	—	—	84	—	55

* Decomposes.

TABLE VIII.—AROMATIC MONOBASIC ACIDS

Acid	Formula	M.P.	Ethyl Ester		Methyl Ester		Chloride		Anhydride M.P.	Amide M.P.	Anilide M.P.
			M.P.	B.P.	M.P.	B.P.	M.P.	B.P.			
Benzoic	$C_6H_5{\cdot}CO_2H$	121	—	211	—	195	—	198	42	128	163
o-Toluic	$CH_3{\cdot}C_6H_4{\cdot}CO_2H$	105	—	220	—	—	—	211	36–38	139	125
p- ,, ...	,,	179	—	228	32	217	—	214	—	158	145
Phenyl-acetic ..	$C_6H_5{\cdot}CH_2{\cdot}CO_2H$	76	—	226	—	220	—	102·5 (17 mm.)	72·5	155	117
o-Chlor-benzoic ..	$C_6H_4Cl{\cdot}CO_2H$	138	—	243	—	230	—	235	—	139	114
m- ,, ..	,,	153	—	245	21	114	—	225	—	133	—
p- ,, ..	,,	234	—	—	42	—	—	220	—	170	194
o-Brom-benzoic ..	$C_6H_4Br{\cdot}CO_2H$	150	—	254	—	246	—	241	—	156	142
m- ,, ..	,,	155	—	259	32	122	—	239	—	151	137
p- ,, ..	,,	251	—	262	74	—	42	245	213	186	197
o-Nitro-benzoic ..	$NO_2{\cdot}C_6H_4{\cdot}CO_2H$	148	30	—	—	—	—	—	135	176	—
m- ,, ..	,,	141	47	298	70	279	35	184 (50 mm.)	—	143	154
p- ,, ..	,,	240	57	—	96	—	75	202 (105 mm.)	—	198	204
Hydrocinnamic ..	$C_6H_5{\cdot}(CH_2)_2{\cdot}CO_2H$	48·5	—	249	—	239	—	119 (13 mm.)	—	82	92
Unsaturated—											
Cinnamic ..	$C_6H_5CH{:}CH{\cdot}CO_2H$	133	12	271	36	260	36	154 (25 mm.)	135	147	151
Atropic	$CH_2{:}C(C_6H_5){\cdot}CO_2H$	106	—	—	—	—	—	—	—	—	—
Phenyl-propiolic	$C_6H_5C\vdots C{\cdot}CO_2H$	136	—	—	—	—	—	130 (25 mm.)	—	100	126

TABLE IX.—DIBASIC ACIDS, ALIPHATIC AND AROMATIC

Acid	Formula	M.P.	Normal Methyl Ester		Normal Ethyl Ester		Anhydride M.P.	Amide M.P.	Imide M.P.	Anilide M.P.
			M.P.	B.P.	M.P.	B.P.				
Aliphatic—										
Carbonic ..	$CO(OH)_2$	—	—	91	—	126	—	132	—	235
Oxalic ..	$CO_2H{\cdot}CO_2H$	98	54	163	—	186	—	(dec.)	—	245
Malonic ..	$CO_2H{\cdot}CH_2{\cdot}CO_2H$	132	—	182	—	198	—	170	—	224
Succinic ..	$CO_2H{\cdot}(CH_2)_2{\cdot}CO_2H$	185	18	195	—	217	119	242	126	227
Glutaric ..	$CO_2H{\cdot}(CH_2)_3{\cdot}CO_2H$	97·5	—	—	—	236	56	176 (dec.)	60	224
Malic	$CO_2H{\cdot}CH_2{\cdot}CH(OH){\cdot}CO_2H$	100	—	122 (10 mm.)	—	128 (10 mm.)	—	—	—	197
Tartaric ..	$CO_2H{\cdot}(CH{\cdot}OH)_2{\cdot}CO_2H$	168	48	280	—	280	—	—	—	263
Aromatic—										
Phthalic ..	$C_6H_4{<}(CO_2H)_2$ (1:2)	184	—	282	—	295	128	—	233	231 (dec.)
Iso-phthalic ..	,, (1:3)	300	64	(dec.)	—	285	—	265	—	250
Tere-phthalic..	,, (1:4)	—	140	—	44	—	—	—	—	—

Recognition of Acids.

The majority of organic acids are sparingly soluble in water and can readily be isolated and purified by methods already indicated, their equivalents and melting-points determined and derivatives prepared (cf. Tables VII–IX).

For acids which are readily soluble in water and hence difficult to isolate quickly in pure form, precipitation methods may be employed for their identification. The aqueous solution of the acid is carefully neutralized with sodium hydroxide, and portions tested with bench solutions of (*a*) $CaCl_2$, (*b*) $Ba(NO_3)_2$, (*c*) $FeCl_3$, (*d*) $AgNO_3$. The formation of precipitates for a number of common acids is given in Table X.

TABLE X

Acid	Ca	Ba	Fe‴	Ag
Formic ..	No pp.	No pp.	Red sol. pp. on boiling	White pp. (r)†
Acetic ..	,,	,,	,,	No pp.
n-Butyric	No pp. in cold*	,,	Red pp.	White pp.
Lactic ..	No pp.	No pp.	No pp. or coloration	No pp.
Oxalic ..	White pp.	White pp.	,,	White pp.
Malonic ..	No pp.	,,	,,	,,
Succinic ..	White pp.	,,	Pale red pp.	,,
Malic ..	No pp.	No pp.	No pp. or col.	,,
Tartaric ..	White pp.	White pp.	,,	,,
Citric ..	No pp. in cold, pp. on boiling	,,	,,	White pp. (r)† on boiling
Hydrocyanic	No pp.	No pp.	,,	White pp.
Hydroferro-cyanic	No pp.	,,	Prussian blue pp.	,,
Hydroferri-cyanic	,,	,,	No pp.‡	,,
Thiocyanic	,,	,,	Deep red col.	,,

* Ca *n*-Butyrate is more sol. in cold than in hot water. A precipitate may therefore appear on warming.

† Precipitates of Ag salts should be dissolved by careful addition of ammonia and warmed to detect reduction (r).

‡ Deep blue pp. with a ferrous salt.

TABLE XI.—ALDEHYDES AND THEIR DERIVATIVES

	Formula	M.P.	B.P.	Melting-points of				
				Semi-carbazone	Phenyl-hydrazone	2:4-Dinitro-phenyl-hydrazone	Oxime α	Oxime β
Aliphatic—								
Formaldehyde*	$HCHO$	—	-21	169(d)	—	168	—	—
Paraformaldehyde [a] ..	$(CH_2O)_3$	121–3	—	—	—	—	—	—
Metaformaldehyde [b] ..	$(CH_2O)n_3$	64	—	—	—	—	—	—
Acetaldehyde	$CH_3{\cdot}CHO$	—	21	163	63	168	47	—
Paraldehyde	$(C_2H_4O)_3$	—	124	—	—	—	—	—
Metaldehyde†	(C_2H_4O)	112(s)	—	—	—	—	—	—
Propaldehyde	C_2H_5CHO	—	49	89	—	155	—	—
Acrolein	$CH_2{:}CH{\cdot}CHO$	—	52	171	—	165	—	—
Crotonaldehyde ..	$CH_3{\cdot}CH{:}CH{\cdot}CHO$	—	104	201	56	190	119	—
Aldol	$CH_3{\cdot}CHOH{\cdot}CH_2{\cdot}CHO$	—	77 (16 mm.)	194	—	—	—	—
Glyoxal	$CHO{\cdot}CHO$	—	—	—	177‡	327‡	—	—
Methylglyoxal	$CH_3CO{\cdot}CHO$	—	—	—	145‡	—	—	—

Aromatic—								
Benzaldehyde	$C_6H_5{\cdot}CHO$	—	179	214	156	235	35	125
o-Tolylaldehyde ..	$C_6H_4(CHO)CH_3(1{:}2)$	—	200	224	—	194	49	—
m- ,, ...	,, (1:3)	—	199	216	91	—	60	—
p- ,, ...	,, (1:4)	—	204	234	113	234	80	—
p-Cuminaldehyde ..	$C_6H_4(CHO)C_3H_7(1{:}4)$	—	235	210	129	243	58	—
o-Nitrobenzaldehyde ..	$C_6H_4(CHO)NO_2(1{:}2)$	44	—	256	153	—	103	154
m- ,, ...	,, (1:3)	58	—	246	120	—	121	—
p- ,, ...	,, (1:4)	106	—	220	155	320	182	133
Salicylicaldehyde ..	$C_6H_4(CHO)OH(1{:}2)$	-	197	225	143	248	57	—
p-Hydroxy-benzaldehyde	,, (1:4)	115	—	224	177	157	72	—
Protocatechnic aldehyde	$C_6H_3(CHO)(OH)_2(1{:}3{:}4)$	153	—	—	175	—	149	—
Anisic aldehyde ..	$C_6H_4(CHO)(OCH_3)(1{:}4)$	—	248	210	121	253	—	—
Vanillin	$C_6H_3(CHO)(OCH_3)OH(1{:}3{:}4)$	81	285	229	105	271	117	—
Piperonal	$C_6H_3(CHO)(CH_2O_2)(1{:}3{:}4)$	37	263	233	103	266	110	—
Phenylacetic aldehyde..	$C_6H_5CH_2{\cdot}CHO$	—	194	156	58	121	103	—
Hydrocinnamic aldehyde	$C_6H_5CH_2{\cdot}CH_2{\cdot}CHO$	—	224	131	—	—	94	—
Cinnamic aldehyde ..	$C_6H_5CH{:}CH{\cdot}CHO$	—	246	215	168	255	138	—
Furfural	$C_4H_3O{\cdot}CHO$	—	161	203	98	229	—	—
Citral (geranial) ..	$C_9H_{15}CHO$	—	226	164	—	116	—	—

[1] "Formalin" is 40 per cent solution. [a] Solid: sublimes under 100°. [b] Trioxymethylene. † "Meta". ‡ Osazone.

TABLE XII.—KETONES, QUINONES AND THEIR DERIVATIVES

	Formula	M.P.	B.P.	Melting-points of Semi-carbazone	Phenyl-hydrazone	2:4-Dinitro-phenyl-hydrazone	Oximes α	Oximes β	
Aliphatic—									
Acetone	$CH_3{\cdot}CO{\cdot}CH_3$	—	56	187	42	128	59	—	—
Methylethyl ketone ..	$CH_3{\cdot}CO{\cdot}C_2H_5$	—	78	135	—	115	—	—	—
Methyl-*n*-propyl ketone	$CH_3{\cdot}CO{\cdot}C_3H_7(n)$	—	102	108	—	143	—	—	—
Methyl-*iso*-propyl ,, ..	,, (i)	—	94	112	—	117	—	—	—
Diethyl ketone	$C_2H_5{\cdot}CO{\cdot}C_2H_5$	—	101	139	—	156	—	—	—
Mesityl oxide	$CH_3{\cdot}CO{\cdot}CH{:}C(CH_3)_2$	—	130	156	—	203	—	—	—
Diacetone alcohol ..	$(CH_3)_2{\cdot}C(OH){\cdot}CH_2{\cdot}CO{\cdot}CH_3$	—	164	—	—	202	56	—	—
Aromatic—									
Acetophenone	$C_6H_5{\cdot}CO{\cdot}CH_3$	20·5	202	167	105	249	59	—	—
Benzophenone	$C_6H_5{\cdot}CO{\cdot}C_6H_5$	48	306	164	137	238	140	—	—
Benzalacetone	$CH_3{\cdot}CO{\cdot}CH{:}CH{\cdot}C_6H_5$	42	260	186	156	227	115	—	—
Dibenzalacetone ..	$C_6H_5CH = CH{\cdot}CO{\cdot}CH = CH{\cdot}C_6H_5$	112	—	—	—	178	—	—	—
Benzoin	$C_6H_5CH(OH){\cdot}CO{\cdot}C_6H_5$	137	320	206(d)	156	245	151	—	—

Cyclic—									
Cyclohexanone	$C_6H_{10}O$	—	155	166	77	162	88	—	—
2-Methyl-*cyclo*-hexanone	$C_7H_{12}O$	—	163	196	—	136	43	—	—
3- ,, ,, ,,	,,	—	168	190	94	155	—	—	—
4- ,, ,, ,,	,,	—	169	197	—	—	39	—	—
Camphor (*d*)	$C_{10}H_{16}O$	179	204	236	233	177	120	—	—
Menthone (*l*)	$C_{10}H_{18}O$	—	208	184	53	146	59	—	—
Carvone (*d*)	$C_{10}H_{14}O$	62	230	162	110	190	72	—	—
β-Ionone	$C_{13}H_{20}O$	—	150 (24 mm.)	148	—	—	—	—	—
Diketones—									
Acetylacetone	$CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}CH_3$	—	137	—	—	209*	149*	—	—
Benzoylacetone	$C_6H_5{\cdot}CO{\cdot}CH_2{\cdot}CO{\cdot}CH_3$	61	264	—	—	—	—	—	—
Benzil	$C_6H_5{\cdot}CO{\cdot}CO{\cdot}C_6H_5$	95	346	—	225*	189*	237*	209*	163*
Quinones—									
Benzoquinone	$C_6H_4O_2$	116	—	—	—	—	240(d)*	—	—
Camphorquinone ..	$C_{10}H_{14}O_2$	198	—	—	—	—	—	—	—
Anthraquinone	$C_{14}H_8O_2$	285	—	—	—	—	—	—	—
Phenanthraquinone ..	,,	200	—	—	—	—	—	—	—

* Denotes di- derivatives.

TABLE XIII.—AMINES: PRIMARY AND SECONDARY AND THEIR DERIVATIVES

	Formula	M.P.	B.P.	Melting-points of						
				Acetyl	Benzoyl	p-Toluene sulphonyl	2:4-Dinitrophenyl	Picryl	Picrate	Schiff's Base†
Primary—										
Methylamine	$CH_3{\cdot}NH_2$	—	-6	—	80	77	178	114	215	—
Ethylamine	$C_2H_5{\cdot}NH_2$	—	18	—	69	62	113	84	168	—
Benzylamine	$C_6H_5{\cdot}CH_2{\cdot}NH_2$	—	184	61	106	116	116	142	199	—
α-Phenylethylamine ..	$CH_3{\cdot}CH(C_6H_5){\cdot}NH_2$	—	185	57	120	—	—	—	141	—
Ethylene diamine ..	$CH_2(NH_2){\cdot}CH_2(NH_2)$	—	116	172	249	160	—	230	233	—
Aniline	$C_6H_5NH_2$	—	184	114	163	103	157	179	165	54
o-Toluidine	$C_6H_4(CH_3)NH_2$(1:2)	—	199	109	144	110	126	168	200	oil
m- ,, ...	,, (1:3)	—	199	66	125	114	160	130	195	,,
p- ,, ...	,, (1:4)	45	200	145	158	118	136	165	169	,,
4-m-Xylidene	$C_6H_3(CH_3)(CH_3)NH_2$(1:3:4)	—	215	130	192	—	156	159	209	,,
p- ,, ...	,, (1:4:5)	15·5	213	139	140	119	—	163	171	102
Mesidene	$C_6H_2(CH_3)_3{\cdot}NH_2$(1:2:4:6)	—	229	216	204	—	—	—	190	43
Pseudocumidine ..	,, (1:2:4:5)	63	234	161	167	—	—	169	134	34
o-Chloraniline	$C_6H_4Cl{\cdot}NH_2$(1:2)	—	208	88	99	105	—	169	—	—
m- ,, ...	,, (1:3)	—	236	72	118	138	—	138	177	oil
p- ,, ...	,, (1:4)	70	230	179	192	95	—	178	178	62
o-Bromaniline	$C_6H_4Br{\cdot}NH_2$(1:2)	31	229	99	116	—	—	192	129	—
m- ,, ...	,, (1:3)	17	—	88	120	—	—	—	180	—
p- ,, ...	,, (1:4)	64	—	166	202	—	—	188	180	67

o-Nitraniline	$C_6H_4(NO_2)NH_2$ (1:2)	72	—	93	98	137	—	220	73	—
m- ,, ...	,, (1:3)	115	—	154	155	138	—	205	143	73
p- ,, ...	,, (1:4)	145	—	216	197	190	—	216	100	117
o-Phenylamine diamine	$C_6H_4(NH_2)_2$ (1:2)	103	256	186	301	—	—	178	208	106
m- ,, ,,	,, (1:3)	63	283	190	240	—	—	206	184	105
p- ,, ,,	,, (1:4)	140	267	303	>300	—	177	186	—	140
2:4:6-Trichloraniline ..	$C_6H_2Cl_3NH_2$	78	262	206	174	—	—	—	83	—
2:4:6-Tribromaniline ..	$C_6H_2Br_3NH_2$	118	—	232	198	—	—	—	—	—
2:4:6-Trinitraniline ..	$C_6H_2(NO_2)_3NH_2$	188	—	—	—	—	—	—	—	—
Benzidine	$NH_2 \cdot C_6H_4 \cdot C_6H_4 \cdot NH_2$	127	—	317	352	352	243	—	—	—
o-Tolidine	$NH_2(CH_3)C_6H_3 \cdot C_6H_3(CH_3) \cdot NH_2$	128	—	230	196	—	-	—	—	—
α-Naphthylamine ..	$C_{10}H_7NH_2$	50	—	160	161	157	190	198	166	73
β- ,, ...	,,	112	306	133	162	133	179	233	—	102
Secondary—										Nitros-amine
Dimethylamine ..	$CH_3 \cdot NH \cdot CH_3$	—	7	—	42	79	—	138	155	—
Diethylamine	$C_2H_5 \cdot NH \cdot C_2H_5$	—	56	—	—	60	—	164	—	—
Methylaniline	$C_6H_5NH \cdot CH_3$	—	194	101	63	95	165	108*	144	15
Ethylaniline	$C_6H_5NH \cdot C_2H_5$	—	206	53	60	88	—	105	137	—
Methyl-o-toluidine ..	$CH_3 \cdot C_6H_4NH \cdot CH_3$	—	207	56	66	—	155	165	90	—
Methyl-p-toluidine ..	,,	—	208	83	—	—	—	145	131	54
Ethyl-o-toluidine ..	$CH_3 \cdot C_6H_4NH(C_2H_5)$	—	214	—	—	—	114	—	—	—
Ethyl-p-toluidine ..	,,	—	217	—	—	—	120	—	—	—
Diphenylamine ..	$C_6H_5 \cdot NH \cdot C_6H_5$	54	302	100	180	142	—	63	182	67
Benzylaniline	$C_6H_5CH_2 \cdot NH \cdot CH_2 \cdot C_3H_5$	37	299	58	107	—	—	—	—	—
Piperidine	$C_5H_{10} \cdot NH$	—	105	—	48	—	—	97	152	—
Piperazine	$NH \cdot C_4H_8 \cdot NH$	104	145	134	191 (dl)	—	—	—	280	-

* Dimorphic form, 128°. † Benzylidene compound.

TABLE XIV.—TERTIARY AMINES

			M.P. of compound with			
		B.P.	Methyl Iodide	Picric acid	1:3:5-Trinitrobenzene	M.P. *p*-Nitroso-compound
Trimethylamine	$(CH_3)_3N$	3·5	230	216	—	—
Triethylamine	$(C_2H_5)_3N$	89	—	173	—	—
Dimethylaniline	$C_6H_5N(CH_3)_2$	193	228	162	109	85
Methylethylaniline	$C_6H_5N(CH_3)C_2H_5$	201	125	134	—	67
Diethylaniline	$C_6H_5N(C_2H_5)_2$	214	102	142	42	84
Dimethyl-*o*-toluidine ..	$CH_3{\cdot}C_6H_4N(CH_3)_2$	184	—	122	—	—
,, -*m*- ,, ..	,,	207	177	—	—	92
,, -*p*- ,, ..	,,	211	220	130	124	—
Benzyl-methylaniline ..	$C_6H_5N(CH_3)CH_2C_6H_5$	306	164	127	—	56
Benzyl-ethylaniline ..	$C_6H_5N(C_2H_5){\cdot}CH_2{\cdot}C_6H_5$	286	161	111	—	62
Methyldiphenylamine ..	$(C_6H_5)_2NCH_3$	296	—	—	—	44
Triphenylamine	$(C_6H_5)_3N$	127*	—	—	—	—
Dimethyl-α-naphthylamine	$C_{10}H_7N(CH_3)_2$	272	—	145	—	—
Dimethyl-β-naphthylamine	,,	46*	—	200	—	—
Pyridine	C_5H_5N	115	117	167	—	—
α-Picoline	$C_5H_4(CH_3)N$	129	230	169	—	—
Collidine	$C_6H_2(CH_3)_3N$	172	—	—	—	—
Quinoline	C_9H_7N	239	72	203	—	—
Isoquinoline	,,	240	159	222	88	—
8-Hydroxy-quinoline ..	$C_9H_6(OH)N$	75*	143	204	—	—

* Melting-point.

Diamines.—The majority of these are aromatic, and the *o*-, *m*-, and *p*- compounds show distinct reactions. With ferric chloride (10 per cent solution) *o*- and *m*-diamines give red colorations, whereas the *p*-compounds yield an odour of a quinone.

TABLE XV.—DIAMINES

	M.P.	Diacetyl Derivative M.P.	Dibenzoyl Derivative M.P.
o-Phenylene-diamine	102	185–186	301
m- ,, ,, ...	63	191	240
p- ,, ,, ...	147	above 295	above 300
2:4-Diamino-toluene	99	224	224
3:4- ,, ,, ...	88	210	263
Benzidine, $NH_2{\cdot}C_6H_4{\cdot}C_6H_4{\cdot}NH_2$	122	317	sublimes
o-Tolidine $NH_2{\cdot}C_6H_3Me{\cdot}C_6H_3Me{\cdot}NH_2$	128	314 tetra- 211	—

The Alkaloids (S.B. Chap. LVIII).

General Tests for Alkaloids.—They are characterized as a group by their bitter astringent taste, and by their poisonous properties. The majority are optically active. With the exception of coniine and nicotine they are not readily soluble in water, but dissolve in mineral acids, and may be thrown down from solutions of their salts on the addition of ammonium hydroxide. Precipitates are formed with the following reagents:

1. A solution of iodine in potassium iodide solution; the precipitates are brown and flocculent.

2. Potassium mercuric iodide; white or yellowish-white precipitates.

3. Phosphomolybdic acid; light to brownish-yellow precipitates.

Tests for Specific Alkaloids.

Coniine, $C_8H_{17}N$, b.p. 167°, sparingly soluble in water; the solution precipitates metallic hydroxides from solutions of their salts like ammonia. Chlorine water gives a copious white precipitate, easily soluble in hydrochloric acid.

Nicotine, $C_{10}H_{14}N_2$, is a colourless lævo-rotatory oily liquid, b.p. 247°; its aqueous solutions precipitate hydroxides from metallic salt solutions.

By gently warming 1 drop of nicotine with 3 or 4 drops of hydrochloric acid (sp. gr. 1·12) a brownish-red solution is obtained. If after cooling a drop of concentrated nitric acid be added, the solution becomes violet-red, gradually changing to red.

Chlorine water gives only a white turbidity or slight precipitate with an aqueous solution of nicotine, which immediately disappears on the addition of hydrochloric acid.

Morphine, $C_{17}H_{19}O_3N + H_2O$.—Small prisms, sparingly soluble in water.

0·1 g. of ammonium molybdate dissolved in 1 ml. of concentrated sulphuric acid gives a deep violet colour with a trace of morphine, which gradually changes to olive green, and finally to a deep blue.

1 part of morphine with 6–8 parts of cane sugar and a few drops of concentrated sulphuric acid give a rose-red to purple-red solution, the intensity of the colour depending on the amount of morphine added.

Quinine, $C_{20}H_{24}O_2N_2 + 3H_2O$, sparingly soluble in water. M.p. 67°, or anhydrous m.p. 177°. Dilute solutions of its salts exhibit a bluish fluorescence.

The addition of concentrated chlorine water ($\frac{1}{5}$ its volume) to a solution of a quinine salt does not colour the solution, but on adding concentrated ammonia solution to this an intense emerald-green colour is produced.

A quinine salt when dissolved in acetic acid and treated with an alcoholic solution of iodine gives after a short time a black crystalline powder (plates).

Cinchonine, $C_{19}H_{22}ON_2$.—White prisms or needles; almost insoluble in water. The solutions of its salts do not exhibit fluorescence.

Chlorine water gives no reaction, but on addition of ammonia a yellowish-white precipitate is formed.

Strychnine, $C_{21}H_{22}O_2N_2$.—White prisms, m.p. 284°.

A few drops of concentrated sulphuric acid added to a little strychnine in a porcelain dish dissolve it without coloration; addition of a little powdered potassium chromate gives a magnificent blue-violet coloration.

Brucine, $C_{23}H_{26}O_4N_2 + 4H_2O$.—Transparent prisms. The anhydrous base has m.p. 178°.

A solution of a brucine salt mixed with a solution of mercurous nitrate gives a colourless solution, which on gently

heating in a water bath gradually gives a beautiful carmine colour. (No coloration is produced by strychnine.)

Chlorine water gives a bright-red solution; addition of ammonia changes this to yellowish-brown.

F. Compounds with Double Functions

A compound may, as has already been pointed out, have the chemical properties characteristic of two (or more) distinct groups of compounds, owing to the presence of two (or more) different atomic groupings, and the student must be on the lookout for such compounds. A few examples of these types of compounds are:

1. **Acid** and **Acid Amide.**—Such are the *amic acids* derived from dibasic acids (S.B. Chaps. X and XXVI). Oxamic acid, m.p. 210°; succinamic acid, no definite melting-point; carbamic acid, dec. 60°; phthalamic acid, m.p. 148°.

2. **Acid** and **Amine.**—(*a*) No sulphur present. Aminocarboxylic acids: as a rule, soluble in both dilute acids and dilute alkalis. Examples: Aminoacetic acid (glycine) (S.B. 243); α-aminopropionic acid (alanine), m.p. 255°; aspartic acid or aminosuccinic acid (Chap. X, 3); *o*-aminobenzoic acid or anthranilic acid, and the isomeric *m* and *p* acids. Compounds closely related to the above are the corresponding acetyl and benzoyl derivatives: one of the commonest of these is hippuric acid or benzoylglycine (S.B. Chap. XXVI, A, 1), m.p. 187°.

(*b*) Sulphur present. Aminosulphonic acids—the commonest of these is sulphanilic acid (aniline *p*-sulphonic acid); metanilic acid (aniline-*m*-sulphonic acid); naphthionic acid (1-naphthylamine-4-sulphonic acid); amide, m.p. 206°; R-acid (2-naphthylamine-3:6-disulphonic acid); G-acid (2-naphthylamine-6:8-disulphonic acid). Most of these crystallize from water, form soluble alkali salts, and can be diazotized and converted into azo-dyes. As a rule, they have no basic properties, as the acidic sulphonic acid groups more than counterbalance the basic amino-groups. They have no definite melting-points, and can only be further characterized by conversion into derivatives.

(*c*) An interesting example of *ester* and *amine* is ethyl carbamate (urethane), $NH_2 \cdot CO \cdot OEt$, which melts at 50°.

3. **Salt** and **Ester.**—The acid esters derived from dibasic

acids can form metallic salts, e.g. potassium ethyl succinate, $CO_2K{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2Et$. Such compounds are recognized by the presence of the metallic radical and by the products of hydrolysis, e.g. in the above case ethyl alcohol and succinic acid.

N.B.—Similar compounds derived from dibasic mineral acids are also met with, e.g. potassium ethyl sulphate, $OK{\cdot}SO_2{\cdot}OEt$, a well-defined crystalline compound. This will give the reactions for the sulphate ion only after hydrolysis.

4. **Acid** (or salt) and **Anilide** (toluidide, &c.), e.g. anilic acids derived from dibasic acids. Oxanilic acid (S.B. Chap. XXI, F), succanilic acid. On complete hydrolysis, e.g. with concentrated hydrochloric acid, they yield the amine (aniline, &c.), and the acid (oxalic, succinic, &c.).

5. **Ketone** and **Acid,** or **Ketone** and **Ester.**

TABLE XVI

Examples	M.P. or B.P.	Phenyl-hydrazone M.P.	Semi-carbazone M.P.
Pyruvic acid, $CH_3{\cdot}CO{\cdot}CO_2H$	b. 165–170	192	—
Ethyl acetoacetate, $CH_3{\cdot}CO{\cdot}CH_2{\cdot}CO_2Et$	decomposes	—	129 (dec.)
Lævulic acid, $CH_3{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}CO_2H$	m. 33	—	187 (dec.)
Ethyl oxalacetate, $COOEt{\cdot}CO{\cdot}CH_2{\cdot}COOEt$	132 (24 mm.)	77	oil
Benzoyl-formic acid,* $C_6H_5{\cdot}CO{\cdot}CO_2H$	oil unstable	—	—
Benzoyl-acetic acid,† $C_6H_5{\cdot}CO{\cdot}CH_2{\cdot}CO_2H$	m. 103	—	—

8. **Phenol** and **Alcohol,** or **Phenol** and **Ether.**—Saligenin (*o*-hydroxy-benzyl alcohol), m.p. 82°, gives a deep blue colour with $FeCl_3$. Guaiacol (*o*-hydroxy-anisole), $OH{\cdot}C_6H_4{\cdot}OMe$, b.p. 220°, has reducing properties, and gives a green coloration with ferric chloride. Eugenol (3-methoxy-4-hydroxyl-cinnamene), $(OH)(OMe){\cdot}C_6H_3{\cdot}CH{:}CH_2$, b.p. 247°, has an odour of cloves, and gives a blue coloration with ferric chloride.

* When heated yields carbon monoxide and benzoic acid.

† When heated above melting-point yields carbon dioxide and acetophenone.

TABLE XVII

6. Phenol and Acid.

	M.P.	Methyl Ester	Ethyl Ester	Amide M.P.	Anilide M.P.	Acetyl Derivative M.P.
Salicylic acid	159	b. 224	b. 231	138	134	118
m-Hydroxy-benzoic acid	200	—	m. 72	167	154	127
p- " "	210	m. 131	m. 112	162	196	185
Gallic (2:3:4-trihydroxy-benzoic) acid	222–240	192	m. 90 or 141 (anhyd.)	243	207	151

TABLE XVIII

7. Phenol and Aldehyde.

	M.P.	Phenyl-hydrazone M.P.	Acetyl Derivative M.P.	Benzoyl Derivative M.P.	With $FeCl_3$
Salicylaldehyde or *o*-hydroxy-benzaldehyde ..	b. 196	142	37	boils above 360	violet
Protocatechuic aldehyde, 3:4-dihydroxy-benzaldehyde	150	176	—	—	green
Vanillin, 3-methoxy-4-hydroxy-benzaldehyde ..	80	105	77	75	blue-violet, and when warmed white precip.

9. **Amine** and **Phenol.**—Examples: *p*-amino-phenol (Exp. 274), m.p. 184°; *p*-methylamino-phenol, m.p. 87°.

10. **Alcohol** and **Aldehyde,** or **Alcohol** and **Ketone.**—To this category belongs the important group of carbohydrates.

11. **Acid** and **Phenolic Ether.**—Anisic acid, *p*-$OMe{\cdot}C_6H_4{\cdot}CO_2H$, m.p. 184°.

Carbohydrates

If the substance is non-volatile and chars when strongly heated, emitting an odour of burnt sugar, it is in all probability a carbohydrate (S.B. Chap. XIV). If soluble in water, yielding a solution with a sweet taste, it will indicate a mono- or di-saccharide; if insoluble in water, a polysaccharide, e.g. starch, cellulose.

With the exception of sucrose and inulin all the common carbohydrates soluble in water reduce Fehling's solution and ammoniacal silver solutions.

The following is a general test for soluble carbohydrates: *Molisch's test.* 2–3 drops of a saturated alcoholic solution of α-naphthol are added to 2 ml. of a very dilute aqueous solution of the carbohydrate, and a few ml. of concentrated sulphuric acid are poured down the side of the tube, so as to form a separate layer. A deep violet-coloured ring is formed, and this coloration spreads gradually throughout the liquid.*

Monosaccharides.—The following reactions may be made use of in order to distinguish a *pentose*:

(*a*) Distil a small amount of the sugar with a mixture of concentrated hydrochloric acid (1 vol.) and water (2 vol.), and test the distillate for furfuraldehyde, e.g. add a few drops of aniline and hydrochloric acid (concentrated), and observe whether a deep red coloration is produced.

(*b*) A small amount of the sugar solution is warmed with orcinol and sufficient hydrochloric acid (concentrated) to make the final concentration of the acid about 18 per cent. If a pentose is present, a red, then violet, and ultimately a bluish-green coloration is produced. A bluish-green precipitate is also formed, and this dissolves in amyl alcohol to a blue-green solution.†

Ketoses and **aldoses** may be differentiated by means of the following reactions:

* *Neuberg*, Z. physiol. 1901, **31**, 565. † *Tollens*, A. 1890, **260**, 395.

1. Ketoses (e.g. fructose) react with methylphenyl-hydrazine, $C_6H_5N(CH_3)\cdot NH_2$, yielding sparingly soluble *yellow* methylphenyl-osazones. *Preparation*: 0·9 g. fructose in 5 ml. water and 2 g. of the hydrazine are dissolved in alcohol; 50 per cent acetic acid (2 ml.) is added, and the whole warmed for five to ten minutes and the osazone allowed to crystallize. Aldoses under similar conditions yield *colourless* methylphenyl hydrazones and not osazones.*

2. Ketoses (1 part) and sugars which yield ketoses, when warmed with resorcinol (0·5 part) and a little water and concentrated hydrochloric acid, give a deep red coloration, and ultimately a brown-red dye, which is soluble in alcohol (*Seliwanoff*).

3. A small amount of the sugar is heated at 60-70° with 10 ml. of bromine water, the excess of bromine is removed by boiling, and a little very dilute ferric chloride solution is added. If an aldose were originally present a deep yellow coloration due to the presence of a hydroxy-acid is obtained.†

The specific sugar present can only be decided by determining some of the physical constants. Table XIX gives a list of the more important.

As polyhydroxylic compounds, most of the sugars yield acetyl derivatives when heated with acetic anhydride and a little fused zinc chloride (cf. Table XIX).

The common **polysaccharides**, $(C_6H_{10}O_5)_x$, are:

Starch.—It is soluble in boiling water, and yields with free iodine solution a deep blue coloration, which is destroyed when the solution is boiled. It is hydrolysed to *d*-glucose, or a mixture of *d*-glucose and dextrine, when boiled with dilute hydrochloric acid for some ten minutes, or when digested for some time with malt extract. The solution is then able to reduce Fehling's solution.

Inulin, usually obtained from dahlia tubers, is readily soluble in hot water, forms spheroid crystals and gives a brown colour with iodine (cf. Starch). It does not reduce Fehling's solution, but is readily hydrolysed to *d*-fructose by dilute acids.

Glycogen (liver starch) is a white tasteless powder which with water gives colloidal solutions and with iodine gives a wine-red coloration. It does not reduce Fehling's solution and is hydrolysed by boiling dilute acids to *d*-glucose.

* *Neuberg*, B. 1902, **35**, 959, 2626.
† *Berg*. Bull. 1904 [3], **31**, 1216.

TABLE XIX

Sugar	Aldose or Ketose	M.P.	$[\alpha]_D$ *	M.P. of Osazone †	Acetyl Derivative: Number of Acetyl Groups Present	Acetyl Derivative: M.P.	Reduction of Fehling's Solution
Arabinose	A	100	+ 104·5	166	4	liq.	+
Xylose	A	144–145	+ 18	163	4	124	+
Rhamnose	A	93	+ 9	185	—	—	+
d-Glucose	A	144–146	+ 52·7	210	5	111	+
d-Galactose	A	163–164	+ 80·3	186	5	142	+
d-Mannose	A	136	+ 13	210	—	—	+
d-Fructose	K	95	− 95·5	210	5	liq.	+
Sucrose	—	160	+ 66·5/20	—	8	78	− ‡
Maltose + H_2O	A	—	+ 139	206	8	158	+
Lactose + H_2O	A	—	+ 52·5	200	8	95–100	+

* See p. 353. These numbers vary somewhat with temperature and concentration.
† See p. 272. ‡ Reduces after inversion, see Exp. 294.

Cellulose.—Similar to starch, but is soluble in an ammoniacal solution of cupric sulphate.

Dextrines.—There are a number of these intermediate between starch and glucose. They all yield glucose on further hydrolysis, and then reduce Fehling's solution. They are soluble in water, and yield blue, red, or no coloration with iodine.

Glucosides.—These compounds yield glucose together with other products when hydrolysed. The best method is to boil the glucoside with 10 per cent potassium hydroxide solution, or with dilute mineral acid, in a flask fitted with a reflux condenser. The solution may then be tested for glucose and examined for other products of hydrolysis.

Some of the commoner glucosides are:

α-**Methylglucoside,** m.p. 165°; β-**methylglucoside,** m.p. 107°, both of which yield glucose and methyl alcohol when hydrolysed.

Amygdalin, $C_{20}H_{22}O_{11}N$.—M.p. 200°. When hydrolysed with dilute acids it yields *d*-glucose, benzaldehyde, and hydrogen cyanide.

Salicin, $C_{13}H_{18}O_7$.—M.p. 201°. On hydrolysis it yields *d*-glucose and *o*-hydroxy-benzyl alcohol; with very concentrated potash salicylic acid is formed.

Arbutin, $C_{12}H_{16}O_7$.—M.p. 157°. When hydrolysed with dilute sulphuric acid it yields glucose and quinol. Its aqueous solution gives a deep blue coloration with ferric chloride.

Myronic acid, $C_{10}H_{17}O_9NS_2$, is hydrolysed to glucose, sulphuric acid, and allyl thiocyanate, allyl mustard oil (S.B. Chap. XII, D).

XXXVIII. PREPARATION OF REAGENTS

A. Gases and Solutions of Gases

The most convenient method of obtaining large quantities of the commoner gases is from the compressed gases which are sent out in steel cylinders similar to those used for oxygen. The following gases can be obtained in this form: Ammonia, carbon dioxide, chlorine, hydrogen, oxygen, nitrous oxide, sulphur dioxide (in glass syphons).

If the compressed gases are not available, the following methods may be adopted:

1. **Ammonia.**—This is most readily obtained by gently warming concentrated ammonium hydroxide (0·880), and passing the gas through a drying tower containing quicklime.

2. **Carbon dioxide.**—From marble and hydrochloric acid (sp. gr. 1·08), obtained by mixing equal volumes of concentrated acid and water, in a Kipp's generator or other common form of apparatus for generating gases.

3. **Chlorine.**—(*a*) By the action of concentrated hydrochloric acid on lumps of pyrolusite (MnO_2). The pyrolusite is just covered with the acid in a flask fitted with delivery tube and safety funnel, and when very gently warmed over asbestos gauze a regular stream of the gas is obtained, and is purified by passing through two wash bottles, one containing water and the other concentrated sulphuric acid.

(*b*) A regular stream of chlorine can also be obtained by the action of concentrated hydrochloric acid on potassium permanganate or dichromate crystals, 5 parts by weight of acid to 1 of crystals. The mixture requires to be very gently heated, e.g. on a water bath.

4. **Hydrogen chloride.**—This is most easily prepared in a Kipp's apparatus by the action of concentrated sulphuric acid on lumps of ammonium chloride.

5. **Hydrogen bromide solution (hydrobromic acid).**—(*a*) Such a solution is obtained during processes of bromination (see Exp. 37), and can be purified by distillation. Water passes over first, and the temperature rises gradually to 126°, when a solution of hydrobromic acid of constant boiling-point distils over and is collected. It has D 1·47, and contains 47·8 per cent hydrogen bromide.

(*b*) A convenient method of preparation is as follows*: Sulphur dioxide is led into a mixture of 35 ml. of bromine and 200 ml. of water, the end of the delivery tube being about 1 cm. above the surface of the bromine.

$$SO_2 + Br_2 + 2H_2O \rightarrow 2HBr + H_2SO_4.$$

The sulphur dioxide is passed in until the whole is transformed into a pale-yellow homogeneous liquid, which is then

* *Scott*, J. C. S. 1900, 77, 648.

distilled. The sulphuric acid remains in the flask, and the distillate, which may contain traces of sulphuric acid, is redistilled over barium bromide.

(*c*) Dry hydrogen is bubbled through a bottle containing bromine, and the resulting mixture passed through a hard glass tube containing heated platinized quartz. The issuing gas is passed through a U tube containing moist red phosphorus, and then dissolved in water. A saturated solution may readily be obtained in this manner.*

6. **Hydrogen iodide solution (hydriodic acid).**

$$P + 3I + 3H_2O \rightarrow P(OH)_3 + 3HI.$$

11 parts by weight of crystalline iodine are introduced into a small round-bottomed flask, and 1 part of yellow phosphorus is cut into small pieces under water, and after drying with filter paper (care) added gradually to the iodine. The addition of each piece produces a flash of light, and the contents of the flask become liquid. When all the phosphorus has been added the flask is allowed to cool, and 1·5 parts by weight of water are added to the solid phosphorus tri-iodide. If the flask is heated with a very small flame hydrogen iodide is evolved, and is purified by passing through a U tube filled with pieces of glass coated with red phosphorus and a *little* water. The heating can be continued until the contents of the flask are colourless.† If a solution is required, the gas is led by means of a very wide delivery tube (as in fig. 80) or an inverted funnel into cold water. As the gas is very soluble only a relatively small amount of water should be taken. In this way solutions of varying degrees of concentration may be obtained, even solutions saturated at 0° or −10°. Dilute solution may be concentrated by distillation. At 127° a solution of constant boiling-point passes over which contains 57 per cent HI, and has D 1·70.

7. **Nitrous anhydride.**—A mixture of NO and NO_2, which reacts as if it were N_2O_3, is obtained when *lumps* of arsenious oxide (As_4O_6) are warmed very gently with concentrated nitric acid. To remove nitric acid and moisture the gas is passed through an empty flask.

* *Claisen* and *Eisleb*, A. 1913, 401, 28.

† If the heating is continued too long, phosphine and phosphonium iodide are formed and an explosion may occur.

B. Solids

1. **Aluminium chloride,** $AlCl_3$.—Strips of aluminium foil or aluminium turnings, which have been freed from oil by boiling with alcohol and dried, are placed in a wide combustion tube open at both ends. The tube is placed in a furnace, and one end is attached to an apparatus for generating dry hydrogen chloride (cf. this chap., A 4), whilst the other just passes through a cork which closes the mouth of a wide-necked bottle or flask. The cork also carries a bent delivery tube which leads the hydrogen into the air. As soon as the air in the apparatus has been displaced by hydrogen chloride,* the burners are turned on gradually until the whole length of the tube is at a dull red heat. A rapid stream of hydrogen chloride is passed through, and the heating is continued until practically all the aluminium has disappeared. The aluminium chloride is volatilized and carried over into the glass bottle or flask, and is subsequently removed and stored in a dry bottle in a desiccator. If kept in an ordinary stoppered bottle, the chloride is attacked by atmospheric moisture, and becomes covered with a layer of basic chloride or of oxide, and is then of very little use for the Friedel-Crafts' synthesis.

2. **Aluminium-mercury couple** (see Exp. 37).

3. **Ammonium stannochloride,** $(NH_4)_2SnCl_4, 6H_2O$.—A solution of stannous chloride is obtained by dissolving 120 g. granulated tin in 450 g. concentrated hydrochloric acid and 150 ml. of water placed in a large flask and gently heated on a sand bath. When the metal has dissolved the liquid is filtered with the aid of a Buchner funnel, cooled, and the excess of acid neutralized by the gradual addition of concentrated ammonia solution (0·88) and repeated shaking. When a permanent precipitate of stannous hydroxide is noticed the liquid is cleared by the addition of a little concentrated hydrochloric acid and is then evaporated to half its volume. On cooling, crystals of ammonium stannochloride separate, which are removed, washed with a little water and dried. A further crop can be obtained by concentrating the filtrate and washing.

4. **Chromic anhydride,** CrO_3.—One volume of a cold saturated aqueous solution of potassium chromate (K_2CrO_4) is

* If the air is not displaced, the hydrogen formed during the reaction will form an explosive mixture with the air, and a serious explosion will occur.

added gradually, and with constant stirring, to 1·5 volumes of concentrated sulphuric acid. The mixture is allowed to cool, when crystals of the anhydride separate. The liquid is decanted, and the crystals washed with a little nitric acid and dried on porous plate in a desiccator. The oxide forms brilliant scarlet crystals, and is hygroscopic.

5. **Chromyl chloride,** CrO_2Cl_2.—(*a*) A mixture of sodium chloride, potassium dichromate, and fuming sulphuric acid, in the proportions required by the equation,

$$K_2Cr_2O_7 + 4NaCl + 3H_2S_2O_7 \rightarrow 2CrO_2Cl_2 + 2KHSO_4 + 4NaHSO_4,$$

is heated in a retort attached to a condenser and receiver, and the heating continued until coloured liquid no longer distils over. The product is purified by distillation.

(*b*) * Chromic anhydride is dissolved in rather more than the theoretical amount of concentrated hydrochloric acid, and to this solution concentrated sulphuric is added gradually, the mixture being cooled between the additions. After standing for about twenty minutes the heavy layer of chromyl chloride is removed by means of a tap funnel, and is purified by aspirating air through it and subsequent distillation. Yield practically theoretical.

6. **Cuprous chloride** (see Exp. 185), **Cuprous bromide** (p. 241), **Cuprous cyanide** (Exp. 187).

Cuprous iodide, CuI.

$$CuSO_4 + 2KI \rightarrow CuI + I + K_2SO_4.$$

Equivalent amounts of crystallized cupric sulphate and of potassium iodide are dissolved in small amounts of water, and the cold solutions mixed. After a short time the precipitate is removed with the aid of the pump, washed with water and then with alcohol until free from iodine, and finally dried in a steam oven.

7. **Fehling's solution.** (Cf. Exp. 290.)

8. **Lead peroxide,** PbO_2.—A filtered solution of bleaching powder (2 parts) in water (30 parts) is added gradually to a practically boiling solution of lead acetate crystals (1 part) in water (4–5 parts). The addition is continued until the precipitate turns dark brown, and until a small test portion of the clear liquid no longer forms a precipitate with the bleaching powder solution. The precipitate is allowed to settle and the

* *Law* and *Perkin*, P. 1907, **23**, 11.

liquid decanted; it is then washed several times with water, filtered with the aid of the pump, and preserved in the form of a paste.

Determination of the percentage of peroxide in the preparation.

(*a*) A given weight of the peroxide is distilled with concentrated hydrochloric acid, the liberated chlorine is collected in potassium iodide solution, and the free iodine titrated by means of 0·1 N. sodium thiosulphate.

(*b*) About 5 g. of the paste is mixed with a solution of potassium iodide (12 g.), sodium acetate (90–100 g.), and 50 per cent acetic acid (50 ml.). The clear solution is diluted to 250 ml. with distilled water, and 25 ml. titrated with 0·1 N. thiosulphate.

$$PbO_2 + 4HI \rightarrow PbI_2 + 2H_2O + I_2.$$

9. **Lead tetracetate.**—100 g. of glacial acetic acid and 50 g. of acetic anhydride are placed in a beaker fitted with a mechanical stirrer, and 50 g. of red lead oxide gradually added with efficient stirring. The temperature should not be allowed to rise above 65°, and towards the end the beaker should be cautiously heated in order to complete the reaction. The hot solution is filtered rapidly and on cooling lead tetracetate crystallizes out. Yield, 25 g.

10. **Metallic alkyloxides.**

(*a*) *Aluminium* iso-*propoxide*.*—300 ml. of *iso*-propyl alcohol dried by means of barium oxide and containing 1 g. of mercuric chloride is poured over 25 g. of aluminium shavings and heated under reflux until the metal is completely dissolved. If the reaction does not start, a little iodine and copper powder may be added, but as the reaction may become violent a good cooling mixture should be available. The excess of alcohol is removed by distillation, the residue distilled in high vacuum and the aluminium *iso*-propoxide collected in vessels which can be sealed.

(*b*) *Sodium ethoxide* (free from alcohol).†—Sodium dust is prepared by heating metallic sodium with dry xylene in a round-bottomed flask until the hydrocarbon boils vigorously. The flask is then closed with a cork, wrapped in a duster, and vigorously shaken. As much as 50 g. of sodium may be used

* *Reichstein, Amman* and *Trivelli*, Helv. 1932, 15, 264.

† *Brühl*, B. 1902, 35, 3516; 1904, 37, 2066.

in one operation, and after a very few minutes the metal is obtained in the form of a fine powder.

The mixture of xylene and finely divided sodium is diluted with more dry xylene until there is 250 ml. of liquid for each 23 g. of sodium. The flask is then fitted with a cork provided with a stirring arrangement (cf. fig. 94), and also with a reflux condenser, the upper end of which is closed by a cork carrying a dropping funnel and soda-lime tube. The flask is placed in cold water, and the stirrer worked vigorously whilst the theoretical amount (1 mol for each atom of Na) of alcohol, mixed with twice its volume of xylene, is added from the dropping funnel. After several hours all the sodium is used up (warm for a few minutes if necessary), and snow-white sodium ethoxide, C_2H_5ONa, is obtained. The xylene can be removed if necessary by rapid filtration with the aid of the pump.

11. **Nickel catalyst for hydrogenation.**—A solution of 10 g. of nickel nitrate or 9·8 g. of nickel sulphate in 50 ml. of water is mixed with 6 g. of kieselguhr and precipitated at 60° with a solution of 6 g. of sodium carbonate dissolved in 25 ml. of water. The mixture should be kept thoroughly stirred during precipitation. The precipitate is washed free from carbonate, dried at 105°, and heated at 300° in a current of hydrogen. This catalyst is more active than nickel without kieselguhr, and should be prepared just before use or kept under the oil which is to be hardened.

A very much more active form called Raney nickel can be prepared by treating a well-ground sample of a nickel-aluminium alloy of the composition Al_2Ni with sodium hydroxide solution until no more hydrogen is evolved. The finely divided product is repeatedly washed by decantation until neutral, and finally with 95 per cent alcohol. It is pyrophoric when dry and is stored in glass-stoppered bottles.*

12. **Palladium-norite.**—This is an effective catalyst for hydrogenation in the liquid phase, the palladium being deposited on the very active form of carbon known as norite. 2 g. of catalyst prepared as follows is a suitable quantity for the hydrogenation of 10–20 g. of material. In some cases the same catalyst may be used more than once.

2 g. of norite are heated in a dish to remove water and air, cooled in a vacuum desiccator, and quickly transferred to the

* *Covert* and *Atkins*, J. A. C. S. 1932, **54**, 4116.

reduction vessel with 100 ml. of water. This vessel is fixed on a mechanical stirrer and connected to the hydrogen reservoir.

A solution of 0·2 g. palladous chloride dissolved in 0·5 ml. concentrated HCl is added, and further diluted with water in order to avoid actual precipitation of palladium in the liquid. The air is removed from the vessel and hydrogen admitted. After shaking for 20 minutes absorption of hydrogen ceases and the chloride has been reduced to the metal which is deposited in the norite.

The catalyst is filtered, well washed with water, and stored in a vacuum desiccator, where it retains its activity for about

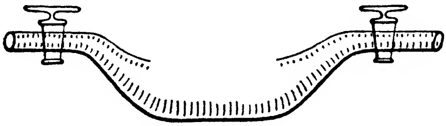


Fig. 98

a fortnight. The material to be reduced is frequently dissolved in alcohol and a suitable reduction vessel is illustrated in fig. 98. If this is not available a bottle with stopper carrying two glass stopcocks may be used.

13. **Phosphorus pentasulphide,** P_2S_5.—The theoretical quantities of sulphur and red phosphorus are mixed in a retort from which the air has been displaced by carbon dioxide, and heated until half the material has distilled over. The distillate consists of phosphorus, sulphur and volatile sulphides of phosphorus, and the residue is the pentasulphide, which is removed from the retort and broken up.

14. **Selenium dioxide.**—5 g. of selenium are treated in an evaporating dish with small quantities of concentrated nitric acid until, under gentle heating, the element goes completely into solution. It is then evaporated completely to dryness, cooled, dissolved in a little water and again evaporated to dryness. The latter operation is necessary in order to remove traces of nitric acid.

15. **Sodium amalgam.**—This alloy is prepared by gently warming dry mercury, placing in a mortar, and adding the theoretical amount of sodium required to form a 2½ or 4 per cent amalgam. The operation should be conducted in a fume

cupboard, and the hand protected by a glove or duster. The sodium is added in small pieces, and produces a vigorous action. It is an advantage to introduce the sodium on the end of a glass rod drawn out to a point, and to press it on the bottom of the mortar if amalgamation does not take place immediately. When prepared it must be protected from atmospheric moisture and carbon dioxide.

16. **Sodium wire.**—A piece of thoroughly clean sodium is placed in the cavity *b* of the sodium press (fig. 99), and by turning the handle (*ee*) is forced through a small opening, and forms a continuous wire which is caught by the vessel placed beneath. After use the press must be thoroughly cleaned and oiled. No trace of alkali must be left.

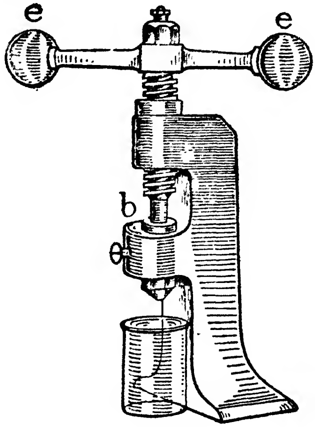


Fig. 99

As sodium oxidizes so rapidly it is often advisable to use freshly sliced metal in preference to the wire.

Suspension of finely divided sodium in toluene.—The flask and apparatus described in Exp. 266 can be used. In the flask are placed 35 g. of sodium and 100 ml. of dry toluene. The mixture is heated in an oil bath until the sodium melts. The stirrer is then started, and when the sodium is finely divided the oil bath is removed and the mixture allowed to cool, stirring being continued during the cooling in order to keep the sodium finely divided.

When the temperature reaches 60°, Exp. 266 may be begun.

17. **Zinc dust,** evaluation of. The value of zinc dust as a reducing agent depends to a large extent upon the percentage of metallic zinc present. This is most readily determined by measuring the volume of hydrogen evolved when a known weight of the dust is dissolved in dilute acid. The apparatus shown in fig. 82 may be used.

18. **Zinc-copper couple.** See Exp. 14. This may be replaced with advantage by the aluminium-mercury couple (Exp. 37).

APPENDIX

TABLE XX.—PRESSURE OR TENSION OF AQUEOUS VAPOUR AT DIFFERENT TEMPERATURES

$t°$ C.	P. in mm.	$t°$ C.	P. in mm.
0	4·6	16	13·5
2	5·3	18	15·4
4	6·1	20	17·4
6	7·0	22	19·7
8	8·0	24	22·2
10	9·2	26	25·0
12	10·5	28	28·1
14	11·9	30	31·6

TABLE XXI.—VAPOUR PRESSURES OF CONCENTRATED POTASSIUM HYDROXIDE SOLUTIONS AT DIFFERENT TEMPERATURES.

$t°$ C.	40 g. KOH, 100 g. water P. in mm.	49 g. KOH, 100 g. water P. in mm.
10	6·5	5·6
12	7·5	6·5
14	8·4	7·3
16	9·6	8·3
18	10·9	9·5
20	12·4	10·8
22	13·9	12·1

TABLE XXII.—VALUES OF 10^{-3} a (cf. Exp. 145, p. 208)

$t°$ C.	Atmospheric pressure (mm. Hg)										
	750	752	754	756	758	760	762	764	766	768	770
14	44·3	44·1	43·9	43·7	43·5	43·2	43·0	42·8	42·6	42·4	42·2
15	45·9	45·7	45·5	45·3	45·0	44·8	44·6	44·4	44·1	43·9	43·7
16	47·7	47·4	47·2	47·0	46·7	46·5	46·2	46·0	45·7	45·5	45·3
17	49·8	49·6	49·3	49·0	48·8	48·5	48·3	48·0	47·7	47·5	47·2
18	52·6	52·3	52·0	51·7	51·4	51·1	50·8	50·5	50·3	50·0	49·7
19	55·7	55·4	55·0	54·7	54·4	54·1	53·7	53·4	53·1	52·8	52·5
20	59·0	58·6	58·2	57·8	57·5	57·1	56·8	56·4	56·0	55·7	55·4
21	62·8	62·4	62·0	61·5	61·1	60·7	60·3	59·[illegible]	59·5	59·1	58·8

TABLE XXIII.—TABLE FOR DETERMINING THE PERCENTAGE OF FREE SULPHUR TRIOXIDE IN A FUMING SULPHURIC ACID FROM ITS SPECIFIC GRAVITY AT 20°.

Sp. gr.	Per cent Free SO_3	Sp. gr.	Per cent Free SO_3
1·840	8·39	1·890	31·67
1·845	16·08	1·895	32·52
1·850	19·04	1·900	33·09
1·855	22·85	1·910	34·10
1·860	26·45	1·920	37·27
1·865	27·57	1·930	41·56
1·870	28·76	1·940	46·46
1·875	29·95	1·950	49·01
1·880	30·38	1·960	52·29
1·885	31·08	1·970	58·81

TABLE XXIV.—TABLE FOR THE PREPARATION OF A FUMING SULPHURIC ACID OF ANY GIVEN CONCENTRATION.*

If a concentrated sulphuric acid and a fuming sulphuric acid of given strength are provided, it is possible by mixing these in suitable proportions to obtain a fuming acid of lower concentration. The simplest method is by means of the formula $x = 100\frac{b-a}{a-c}$, where x = the number of grams of the concentrated acid which must be mixed with 100 g. of the fuming acid to produce the more dilute fuming acid of required strength. a = the total per cent of SO_3 in the acid required, b the total per cent of SO_3 in the original fuming acid, and c the per cent of SO_3 in the concentrated acid. The values for a, b, c can be obtained from the following tables:

Fuming Sulphuric Acid		Concentrated Sulphuric Acid	
Per cent Free SO_3	Total per cent SO_3	Per cent H_2SO_4	Per cent SO_3
0	81·6	90·0	73·4
2	82·0	90·4	73·8
4	82·4	90·8	74·2
6	82·7	91·0	74·3
8	83·1	91·4	74·7
10	83·4	91·8	75·0
12	83·8	92·0	75·1
14	84·2	92·4	75·4

* *Gerster*, C. Z. 1887, 3; L. C. Spezieller Teil, 1291.

Fuming Sulphuric Acid Per cent Free SO_3	Total per cent SO_3	Concentrated Sulphuric Acid Per cent H_2SO_4	Per cent SO_3
16	84·5	92·8	75·8
18	84·9	93·0	76·0
20	85·3	93·4	76·3
22	85·7	93·8	76·5
24	86·0	94·0	76·6
26	86·4	94·4	77·0
28	86·8	94·8	77·4
30	87·1	95·0	77·5
32	87·5	95·4	77·9
34	87·9	95·8	78·2
36	88·2	96·0	78·3
38	88·6	96·4	78·7
40	89·0	96·8	79·0
42	89·3	97·0	79·2
44	89·7	97·4	79·5
46	90·1	97·8	79·8
48	90·4	98·0	80·0
50	90·8	98·4	80·3
52	91·2	98·8	80·6
54	91·5	99·0	80·8
56	91·9	99·4	81·1
58	92·3	99·8	81·4
60	92·6	100	81·6

If a concentrated acid of 98·2 per cent H_2SO_4, and a fuming acid containing 25·6 per cent SO_3 are provided, and an acid containing 19 per cent SO_3 is required,

$$a = 85{\cdot}1,\ b = 86{\cdot}3,\ c = 80{\cdot}1.$$

$$\text{Then } x = 100\,\frac{86{\cdot}3 - 85{\cdot}1}{85{\cdot}1 - 80{\cdot}1} = 24.$$

So 24 g. of the concentrated acid must be mixed with 100 g. of the given fuming acid to yield the fuming acid of required strength.

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